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The first mile towards access equity: Is on-demand microtransit a valuable addition to the transportation mix in suburban communities?

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ABSTRACT

As cities grow, the benefits of living in them are increasingly unequally distributed. USA cities, in particular, have experienced rapid suburbanization of poverty and decreased levels of access to jobs for transit-dependent and vulnerable communities. The public transit challenges in suburbs call for innovative forms of transit to turn the tide on urban inequality. On-demand microtransit, a novel type of shared mobility provides efficient, convenient and affordable transportation. Its potential for redressing inequity had yet to be investigated fully in a suburban setting. We presented a case study from the suburbs of Minneapolis-St. Paul in Minnesota, USA. We combined unique datasets of microtransit ridership from two public transit agencies, transit surveys, land use data, and expert interviews, to conduct spatial analysis, accessibility analysis, and equity impact assessments for these suburbs. We found that microtransit enables public transit agencies to reach a larger number of vulnerable riders than fixed-route transit, particularly for commuting and trips to/from commercial areas. Microtransit also provided a cheaper alternative to ride-hailing and a faster alternative to public transit and walking, without cannibalizing ridership from fixed-rout transit alternatives. Finally, microtransit redressed transportation inequities by alleviating access inequality, reaching vulnerable rider groups effectively, and creating travel opportunities that are less spatially concentrated than those provided by traditional, fixed-route public transit. This study provided a framework for further investigations into the impact of microtransit, including in urban core or rural settings, and highlighted the impact of microtransit in reducing access inequity in a suburban environment.

1. Introduction

As of 2007, more than half of the world's population lives in increasingly densely populated urban areas (Ritchie and Roser, 2018). Cities offer the prospect of employment, education, and high-quality services and contribute disproportionately to national economies (Moore et al., 2003). However, recent studies also find that extreme urban growth results in a nonlinear economic effect, where urbanization initially leads to more equality, but higher levels of urbanization result in increased degrees of inequality (Heinrich Mora et al., 2021; Liddle, 2017; Sarkar, 2019).

In some North American metropolitan areas, urban economic inequality is highly intertwined with racial segregation and car-centric culture (Stacy et al., 2020). Processes of gentrification have in some cases played a role in pushing both senior and low-income populations out of the urban core and into the suburbs (Nijman and Wei, 2020; Institute on Metropolitan Opportunity, 2019). This process, described as the suburbanization of poverty, poses a principal challenge for urban planning. The situation is made even more problematic by the fact that low-skilled labour predominantly remained located in central cities, thus increasing commute time for, in particular, the low-income population (Li et al., 2013), who traditionally have lower car ownership and higher transit-dependence (Stacy et al., 2020).

These complex urban dynamics create pressure to expand public transit services in the suburbs to keep access levels up to a minimum standard (Kneebone and Berube, 2013; Stacy et al., 2020). However, the starting point is a situation in which there already exists a great disparity in job accessibility for car users versus transit riders (Yan et al., 2022). Besides, low-income riders are already considered a group that is both at risk for transit dependence and a vulnerable rider group, as are seniors, the young, people with disabilities, and the locally disadvantaged (Denmark, 1998). This situation calls for innovative urban and transit planning to counter growing inequality and enhance the access levels of at-risk communities in the suburbs.

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1.1. The definition of accessibility

The concept of accessibility first gained scientific traction in the late 1950s and has been studied extensively since. In a vital work that shaped the field Hansen (1959) defines accessibility as ‘the potential of opportunities for interaction’. Based on this definition as well as subsequent ones and practical measures Geurs and Van Wee (2004) identified four components of accessibility that are theoretically important in measuring accessibility: (i) the land use component, (ii) the transport component, (iii) the temporal component, and (iv) the individual component (Geurs and Van Wee, 2004).

Alongside this conceptual demarcation, researchers and planners alike have focused their efforts on operationalizing accessibility. This has resulted in a range of metrics that can be applied to the urban and transit planning practice (El-Geneidy and Levinson, 2006; Handy and Niemeier, 1997; Koenig, 1980; Levinson and King, 2020; Morris et al., 1979; Stewart, 2014). A few crucial metrics are the *Cumulative opportunity measure* (Hansen, 1959), *Gravity-based measure* (Hansen, 1959), and a range of *Utility-based measures* (Koenig, 1980). Many planners are hesitant to adopt the more mathematical, though methodologically sound, definitions of accessibility, such as the utility-based measures, despite their proven value for policy-making (Boisjoly and El-Geneidy, 2017; Geurs and Van Wee, 2004; Koenig, 1980; Morris et al., 1979). This might lead researchers to choose simpler and more explainable metrics, like cumulative opportunity, to enable a higher policy impact (El-Geneidy and Levinson, 2022; Levinson and King, 2020). This decision can at times be justified. For example, the cumulative opportunity and gravity-based measures have a demonstrated strong correlation (El-Geneidy and Levinson, 2006; Santana Palacios and El-geneidy, 2022) and therefore some encourage the usage of the cumulative measure since it is more communicative and therefore presumed to have a larger policy impact (El-Geneidy and Levinson, 2022; Levinson and King, 2020).

Once operationalized, accessibility metrics can be evaluated as indicators of social equity for transport policy-making (Manaugh et al., 2015). In the process of converting accessibility metrics to measures of equity, the question of what is fair, or equitable, arises. The ethical theories of sufficientarianism as well as egalitarianism have practical applications in the transport domain Martens (2016), Pereira et al. (2017). Following sufficientarianism would imply arguing for a minimum standard of accessibility for every person whereas an egalitarian approach would imply seeking a reduction of inequality altogether. Martens (2016) is a prominent supporter of sufficientarianism, pleading that the government has a duty to provide every person with adequate transportation. Alternatively, Rawls’ egalitarianism (Rawls, 1999, 2001) has been elaborated on by Pereira et al. (2017) in light of transportation equity. Their interpretation states that according to Rawlsian egalitarianism transport policy interventions such as service provision can only be considered fair if they improve the accessibility levels of the least advantaged groups.

As a practical implementation of measuring access equity through an egalitarian worldview, Delbosc and Currie (2011) and Lucas et al. (2016) evaluate access using Lorenz curves and Gini coefficients, signifying the (un)equal distribution of access in a way that is recognizable to policy-makers. Furthermore, to shift from normative aspirations of equality to transportation equity, it would be useful to take into account the impact of interventions for the most vulnerable population alongside these Lorenz curves and Gini coefficients. In conclusion, we propose a comprehensive methodological foundation for measuring equality and equity in access, in particular following the theory of egalitarianism, employing a combination of Lorenz curves and Gini coefficients with consideration for the impact of the transport policy on the least advantaged rider groups. Policy-relevant applications of these methods to new transit types are limited, which provides a compelling case for a new transit type to be studied using these theories.

1.2. On-demand microtransit’s emerging role in the transportation mix

Public transit ridership has fallen significantly across the USA in recent years (TransitCenter, 2018), indicating that fixed-route public transit is not able to keep up with the demand in American cities, especially of vulnerable rider groups (Allen and Farber, 2020; TransitCenter, 2018; Yan et al., 2022). This misfit, in combination with the aforementioned suburbanization of poverty and spatial misalignment between jobs in city centers and housing in suburbs (Li et al., 2013; Stacy et al., 2020), has contributed to the rise of a variety of shared mobility options, all with distinct features and impact on riders (Jin et al., 2018; Shaheen et al., 2020). Ride-hailing, where a car is ‘hailed’ via an app or website, similar to a taxi service, has become very popular in metropolitan areas, with one of the most prominent examples of such a service being Uber. The scientific findings on these services, however, conclude that ride-hailing is predominantly used to travel between highly accessible areas (Marquet, 2020), may appeal mainly to a high-income (Cats et al., 2022) as well as young and highly educated (Rayle et al., 2016) audience, and even suggest that Uber’s role in improving transport equity is insignificant (Jin et al., 2019).

Besides ride-hailing, Shaheen et al. (2020) defines another type of shared mobility, which has repeatedly been mentioned as a mode that can potentially reduce access inequalities (Mayaud et al., 2021; Yan et al., 2022). Microtransit – demand-driven transit enhanced with technology – incorporates flexible routing and scheduling and is often run by publicly funded transit agencies. Rides are mostly, if not always, shared, and the service often involves minibuses instead of cars, making the service cheaper than ride-hailing (Mayaud et al., 2021; Shaheen et al., 2015). Microtransit typically fulfills a bridging function: to serve the first/last mile needs of residents by complementing fixed-route transit in lower density areas (Mayaud et al., 2021; Jin et al., 2018). These distinct characteristics might completely change the impact microtransit has on its riders and the urban environment compared to ride-hailing. Some studies have already been conducted globally: in Helsinki, Haglund et al. (2019) evaluated a microtransit pilot. Results indicated that, for the most part, this service replaced personal car use, though in some cases, it also replaced walking and cycling (Haglund et al., 2019). Recent work by Lazarus et al. (2021) investigated the general potential of microtransit and showcased the widespread growth of microtransit services, specifically in the USA. This work also found the rider profile to be very diverse across different regions, reflecting local differences in the availability of fixed-route public transit and shared mobility services (Lazarus et al., 2021).

1.3. Research aims

As urban inequality increases and marginalized communities are pushed to the suburban environment (Nijman and Wei, 2020), the call for innovative transit modes increases. Extensive case studies on the impact of ride-hailing services on riders, urban environments, and even transport inequality have been conducted in the USA (Cats et al., 2022; Gehrke et al., 2019; Jin et al., 2019; Marquet, 2020; Rayle et al., 2016), but no case study in the USA has focused on microtransit yet, despite its potential to shift the distribution of access (Lazarus et al., 2021; Mayaud et al., 2021; Yan et al., 2022). Additionally, limited methodological frameworks and examples exist to evaluate the access equity impact of such a novel transit type along multiple dimensions. This study aims to fill that gap and answer the question ‘What are the access equity implications of microtransit services in suburban communities?’ by evaluating the access equity impact of on-demand microtransit in a case study suburban area. The research aims can be summarized as:

1. Assess the degree to which microtransit is currently able to reach vulnerable rider groups.

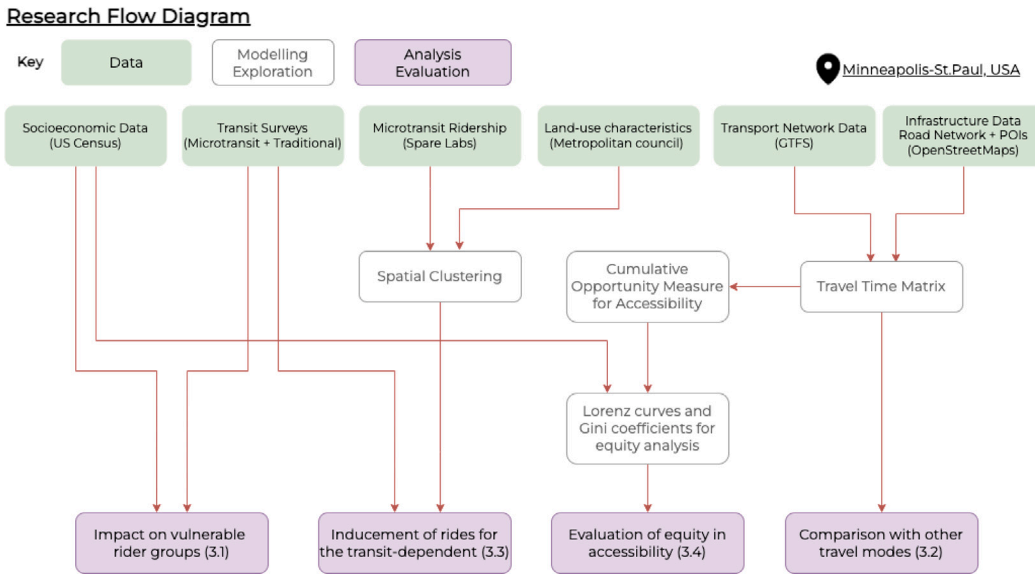


Fig. 1. The research flow diagram, which presents how the data and methodological frameworks come together to provide the results.

2. Evaluate the degree to which microtransit complements and/or competes with other transportation options (ride-hailing, personal car use, fixed-route public transit, and walking) in the suburban environment.
3. Identify the ways in which microtransit enables riders to take rides that are crucial to their socio-economic welfare in suburban areas.
4. Assess the effect of microtransit on access equity in suburban areas.

2. Methodology & data

This section details the general approach, data, and methodological frameworks employed in this study. Fig. 1 shows how the data sources and methodological frameworks were combined to form the results presented in the next section.

2.1. Case study approach

For this study, a case study was conducted in the Southern suburbs of the Minneapolis-St. Paul metropolitan region, USA. In this specific area, two distinct, but non-competing microtransit services had been active for several years as an integrated part of the public transit agencies. Spare Labs Inc. (henceforth referred to as 'Spare'), an on-demand transit technology provider (Spare Labs Inc, 2022), has been providing software for these companies to plan their trips during a significant portion of these years. For this study, a collaboration with Spare was established to utilize a data set on on-demand microtransit usage. This specific case was selected based on: (i) the existence of a well-established and extensive microtransit network, (ii) the availability of large volumes of trip and survey data through the agency, (iii) the availability of fine-grained, and high-quality data on the locations of services, amenities, and employment opportunities and socio-economic indicators of the area, and (iv) regularly updated and freely available fixed-route transit data.

Fig. 2 shows the situation of the areas of study within the larger agglomerate of Minneapolis-St. Paul. It is visible that the fixed-route transit network that is widespread in the central city, has a limited reach in the suburban areas, in particular in area A. Major roads however do find their way into the suburbs and thus provide a more convenient bridge to the city. The areas are relatively affluent, with only 8.8% of the population earning a gross annual household income of less than $25,000, compared to a Minnesota state average of 13% and a national average of 16% (United States Census Bureau, 2022a). In terms of ethnicity and race, 72.9% of the population self-identified as white (alone), whereas 8.4% identified as black or African American, and 8.0% as Asian (United States Census Bureau, 2022a). The Minnesota averages for the same period were respectively 77.5%, 7.0%, and 5.2%, and the national averages were 61.6%, 12.4%, and 6.0% (United States Census Bureau, 2022a). Thus, the neighborhood can be described as relatively white compared to the national average, but relatively mixed when compared to the Minnesota average. Lastly, car ownership was exceptionally high, with only 3.0% of the population indicating that their household did not have a vehicle, and 29.5% indicating they had no or one vehicle, with the remaining 70.5% thus being part of a household with two or more vehicles (United States Census Bureau, 2022a). The studied area can overall be described as a suburban region within a large metropolitan agglomeration, that is relatively affluent, has high car ownership levels, and overall low levels of public transit availability. This general description was confirmed by the transit providers.

2.2. Data collection and processing

This section describes the quantitative and qualitative data sources used in this study, which have been processed in accordance with Fig. 1. Descriptive statistics on the data sets, keywords used to search databases, as well as the questionnaire used by Spare, can be found in the supplementary information document, Section 2.

2.2.1. Microtransit ridership data

Microtransit ridership data were extracted from Spare's operational database. These data featured the locations (latitude and longitude) of trip origins and destinations to 3 decimal points, equivalent to an accuracy of 78.7 meters at the 45 N/S. The user ID was removed from this dataset by Spare owing to personal private information (PPI) regulations governing the sharing of travel information. 257,324 trips were recorded from the period August 2019–April 2022. To clean the data, we removed entries with ride times longer than 2 h, rides with distances longer than 100 miles, rides that were conducted outside of the public transit agencies' service areas, and trips that were not fully completed. After cleaning, a total of 227,022 trips remained.

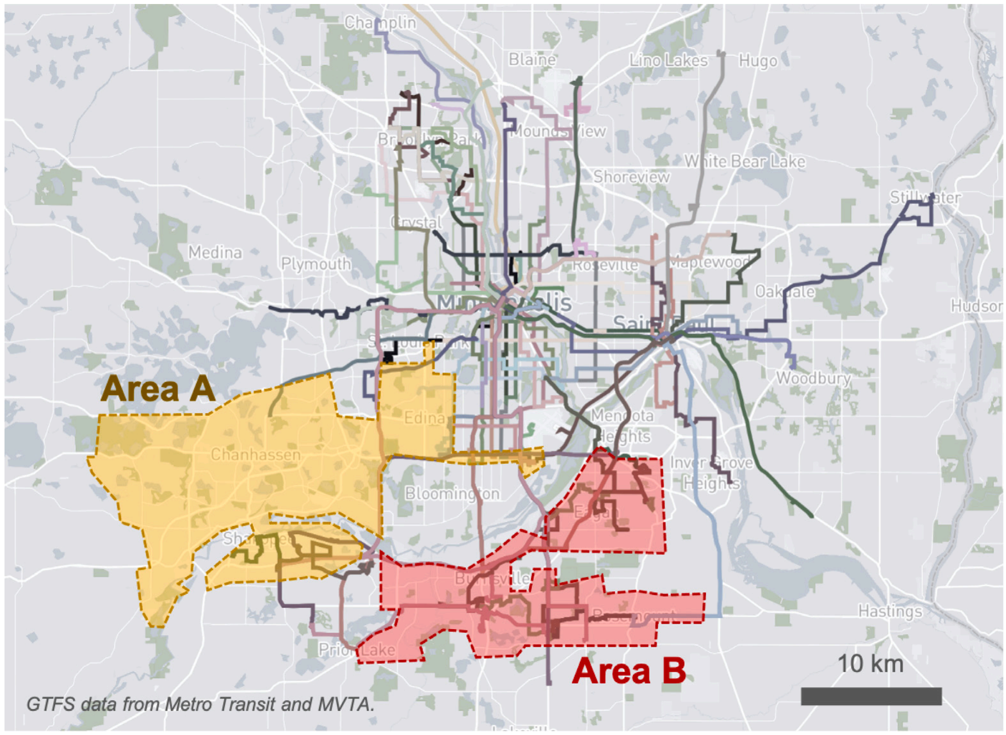


Fig. 2. A map of the study area, highlighting the study areas and the fixed-route transit options of the local agencies MVTA and Metro Transit.

2.2.2. *Microtransit survey data*

Spare deploys digitized travel surveys bi-annually to all microtransit riders via text message (SMS) and matches survey responses to the relevant trip record. 1,479 responses were collected over four rounds of surveys (Oct–Nov 2020, Apr–Jun 2021, Nov 2021, and Apr 2022) and were all included in this analysis. This data includes information on the purpose of the user's trip, age, gender, ethnicity, and annual household income.

2.2.3. *Fixed-route transit and infrastructure data*

Fixed-route transit survey data was extracted from the Travel Behavior Inventory (TBI) Fall 2016 Transit On Board Survey conducted by the Metropolitan Council (Metropolitan Council, 2017). It should be noted that this was the most recent dataset available on this scale, and potential changes in travel patterns due to the Covid-19 pandemic should be considered.

Fixed-route transit routing information was predominantly collected in the form of General Transit Feed Specification (GTFS) files. GTFS is a common format for publishing public transportation schedules (Google, 2022). A large repository of regularly updated GTFS files can be found on Transit.land (Interland Technologies, 2022).

Road infrastructure data was downloaded in the form of OpenStreetMaps (OSM) files. OSM is a community-driven source of GIS data on roads and amenities (OpenStreetMap, 2022). These files were extracted using BBBike (Schneider, 2022). Three extracts were made for differing purposes: two smaller ones of only the service areas themselves and one larger of the entire metropolitan area. This was done to increase computational efficiency when estimating trips within the service area.

2.2.4. *Urban spatial data*

Socio-economic data was collected from the US Census Bureau's 2020 census estimates (United States Census Bureau, 2022a). The Census data set is a high-quality and fine-grained data set counting every person living in the USA and uncovering many socio-economic indicators. The Census data was collected on or aggregated to Block Groups, statistical divisions which generally contain between 600 and 3,000 people (United States Census Bureau, 2023). Specific socio-economic data selected can be found in section 2.4 of the supplementary information document.

Points of interest data on the availability and location of services and amenities were extracted from OSM. This resource is available worldwide though its quality can differ per location. For the points of interest, it was decided to focus solely on jobs, shops, and healthcare facilities. This selection balances accuracy with feasibility: we might expect that other points of interest, such as schools and public facilities, might have been similarly spatially distributed across the area and therefore inclusion of them would have resulted in similar outcomes. The locations of shops and healthcare facilities were extracted using the Overpass-turbo wizard (Nominatim, 2022).

Employment opportunities were extracted from an altered version of the LEHD-LODES data (Census Bureau, 2019). This data set gives the workplace area characteristics, which is a count of jobs available per census block. This was aggregated to census block groups for the entire metropolitan area. This data was slightly older (2019) and does not include informal work. The general zones with high levels of employment opportunities are assumed to be consistent over the 3-year time span and formal/informal work.

Land use was found in the form of the generalized land use inventory of the metropolitan area from 2020 and was fitted to the case study area (Metropolitan Council, 2021) and aggregated in terms of categories. Since this dataset is released every 10 years this was the most recent data available. Land use is also assumed to stay relatively constant over time.

2.2.5. *Semi-structured interviews*

Two semi-structured interviews were conducted with senior employees of the studied microtransit agencies to further grasp the history, position, and motivation for the microtransit network in the case study area. The interviews had the following structure: (i) the interviewer gave a short presentation (5-8 min) on the research, (ii) the interviewees were allowed to ask questions about the presentation and research, (iii) the interviewer asked a selection of questions from a prepared list of questions with a focus on the intended user group and general objectives of the service and its relation to the traditional transit network. The interviews were transcribed and analyzed using data reduction and coding. Interview questions and summaries can be found in the supplementary information document, Section 3.

2.3. Methodology

This section highlights the methodological framework and techniques that were used to process the gathered data and form a set of results. For more details on each individual method, diagrams can be found in the supplementary information document, Section 1.

2.3.1. Investigating the spatial relation between land use and microtransit

To investigate where significant spatial outliers in microtransit demand are located and how these overlap with land use, we conducted two spatial analyses in ArcGIS. The hotspot analysis finds statistically significant cold- and hotspots based on a set of points using the Gets-Ord Gi⋆ statistic. This analysis evaluates each data point within the context of neighboring points and its results include z-scores and p-values indicating where spatial clusters of high or low feature values are located (ArcGIS, 2023b). The second analysis, the outlier- and cluster analysis employs the Anselin Local Moran's I statistic to find and quantify significant clusters of high-high, low-low, high surrounded by low, and low surrounded by high clusters (ArcGIS, 2023a). Both analyses were also mapped in combination with the land-use mapping of the area, to identify similarities between clusters or hotspots and specific land-use types and to match the origins and destinations of the microtransit trips to land-use types.

2.3.2. Evaluating alternative travel times for competition and complementarity

To evaluate the difference in travel time for alternative travel modes to microtransit, we computed a travel time matrix. For this purpose, OpenTripPlanner (OTP) was employed. A graph of the area was built using both infrastructure data from OSM and transit data from GTFS files. The origins and destinations of the microtransit trip data were then used to calculate the alternative driving, walking, and fixed-route public transit travel time for those combinations of origin and destination. A comparison in travel time to ride-hailing, though desirable, was unfeasible. There was no possibility of attaining a ride-hailing dataset with trips similar to the microtransit dataset nor was there a way to artificially generate representative travel times for ride-hailing due to the lack of information on how those travel times would compare to both individual car use and microtransit.

2.3.3. Identifying the level of access with the cumulative opportunity measure

To identify the level of access before and after the addition of on-demand microtransit to the transportation mix, we carried out an accessibility analysis employing the cumulative opportunity measure. This was done by subsequently evaluating the travel time between centroids of census blocks (origins) and points of interest (destinations) with OTP, resulting in a travel time matrix. A column for on-demand microtransit travel time was then added to this matrix by multiplying the car travel time by 1.3. This multiplying factor was based on a comparison between the travel times of 208,394 historical microtransit trips and their personal car counterparts, as estimated by OTP. On average, the travel time for microtransit in these historic trips was 1.3 times longer than for (personal) car use. Once the travel times between origins and destinations were established, accessibility was calculated utilizing a cumulative opportunity measure (Hansen, 1959). The cumulative opportunity measure was selected because of its simplicity of calculation and strong communicative value (Santana Palacios and El-geneidy, 2022). The access levels were calculated for all three opportunity types: jobs, shops, and healthcare facilities.

$$A_{jm} = \sum_{i=1}^{N} O_i * B_{ji}, B_{ji} = \begin{cases} 1 & \text{if } c_{ji} \le T \\ 0 & \text{if } c_{ji} > T \end{cases} \quad (1)$$

In this equation, A_j is used to describe the accessibility level of a specific location j with a specific mode m, which would be one of: car, microtransit, fixed-route public transit, and walking. O_i is the number of opportunities, for example, jobs at locations i. This number of opportunities is multiplied by 1 or 0, depending on whether the travel time to that point is under the threshold value. For the aggregated metric, the threshold T was set at 1 h for access to jobs and healthcare facilities and 30 min for access to shops. This decision was made based on the work by Iacono et al. (2008) in the same study region which showed overall patterns in how long individuals are willing to travel for specific activity types. The aggregated access score was calculated by taking the relative access level (compared to the entire population) for each block group and destination and weighing jobs, shops, and healthcare facilities in accordance with the weighing of the level of access for fundamental needs by Zheng et al. (2019). Thus, the access to the three different opportunities was aggregated as follows:

$$A_j = \frac{A_{j,shops}}{\sum_{n=1}^{N} A_{n,shops}} \times \frac{0.15}{0.37} \times \frac{A_{j,health}}{\sum_{n=1}^{N} A_{n,health}} \times \frac{0.07}{0.37} \times \frac{A_{j,jobs}}{\sum_{n=1}^{N} A_{n,jobs}} \times \frac{0.15}{0.37} \quad (2)$$

In this equation, A_j stands for aggregated access of block group j, $A_{j,shops}$ stands for the access level of that same block group to a specific need type, in this case, shops. N stands for all the block groups within that area.

2.3.4. Evaluating Lorenz curves for equity analysis

To evaluate the access equity impact of on-demand microtransit, we communicated our accessibility analysis using Lorenz curves and Gini coefficients, as suggested by Lucas (2012) and Delbosc and Currie (2011) to enhance potential policy impact. Lorenz curves show the extent to which a certain resource is (un)equally distributed by plotting the cumulative population against the cumulative level of a studied resource. In this case, the cumulative population is plotted against the cumulative level of access. Gini coefficients are calculated by dividing the area between the Loren curve and the line of equality by the total surface below the line of equality. A Gini coefficient of 0, therefore, indicates a completely equal distribution.

No Census data was available that combined the statistics on the number of persons with the number of vehicles per household, which would enable us to create realistic scenarios for the share of the transit-dependent population. Therefore, a hypothetical rather than a realistic scenario was selected to operationalize the Lorenz curves. This scenario assumes that the entire population uses fixed-route public transit or microtransit. Though not realistic, this scenario enables us to demonstrate the degree to which transit services in themselves can be (un)equitable distributed, rather than creating a flawed representation of reality.

3. Results

In this section, the four main research questions established in Section 1 are answered one-by-one employing the methods presented in Fig. 1.

3.1. The impact of microtransit on vulnerable rider groups

By comparing survey results of microtransit and traditional transit riders with the general population survey (US census), we aimed to demonstrate if and how on-demand microtransit was able to reach vulnerable rider groups in the studied suburban area. The vulnerable rider groups studied were selected based on the work by Denmark (1998), which listed the principal vulnerable rider groups as seniors

(65+ years of age), young people (<18 years of age), low-income people (income below $25,000), the locally disadvantaged and those with disabilities. The locally disadvantaged were left out of this section and will instead be discussed in detail in Section 3.4. The low-income and transit-dependent riders were also mentioned during the interviews as initial target groups for the transit providers.

The full distribution of microtransit and fixed-route transit survey respondents across income brackets is shown in Fig. 3(a). A Chi-square independence test showed that income levels differ significantly between microtransit riders and the general population (X^2 =3,044; df = 5; p <.00001), indicating that low-income individuals generally made more use of microtransit. A Chi-square independence test also revealed that the share of low-income riders differed significantly between microtransit riders and fixed-route transit riders (X^2 = 1,267; df = 1; p <.00001), indicating that microtransit drew in proportionally more low-income riders than fixed-route public transit. The threshold for low-income was set at an annual household income of $25,000, based on the average household size in this area (between 2.5 and 3) and the corresponding poverty threshold of the Census Bureau (United States Census Bureau, 2022b): $21,559 for a three-person household. Within our framework, $25,000 was the closest threshold to that number. 55.5% of survey respondents had a household income below $25,000 while in total in this region only 8.2% fell into this income bracket. Additionally, microtransit reached more riders in this income bracket than fixed-route transit did, for which only 14.4% of riders fell into this income bracket.

The full distribution of microtransit and fixed-route transit survey respondents across age brackets is shown in Fig. 3(b). A Chi-square independence test showed that age levels differed significantly between microtransit riders and the general population (X^2 =105; df = 6; p <.00001), as well as between microtransit riders and fixed-route transit riders (X^2 =715; df = 6; p <.00001). Microtransit reached an extremely low number of riders under 18, only 4.3%, even though 24.7% of the general population is younger than 18. Microtransit mainly reached riders in the age brackets 35 to 44 and 55 to 64. Compared to fixed-route transit microtransit reached more 55+ riders and fewer 18–34 riders, thereby reaching a senior rider group, but not necessarily, or to a greater extent than traditional transit, the young.

Self-indicated disability status of microtransit riders was at 33.1% while, according to the Census Bureau, only 7.8% of inhabitants of the area indicated having a disability. The traditional transit survey indicated that fixed-route public transit only reached 5.7% riders with disabilities. A Chi-square independence test showed that reported disability status differed significantly between microtransit riders and the general population (X^2 =1,096; df = 1; p <.00001), as well as between microtransit riders and traditional transit riders (X^2 =1,704; df = 1; p <.00001). This suggests that microtransit managed to be inclusive of riders with disabilities. Microtransit was potentially attractive to riders with disabilities because it is a curb-to-curb service and does therefore not require walking to a stop. In the survey, riders with disabilities more regularly indicated choosing microtransit because it was safer (39%) and better suited to their needs (43%), compared to the overall groups of riders where this was indicated as a reason by respectively 29% and 44%.

3.2. Competition with and complementarity to other travel modes

By combining ridership data with infrastructure and fixed-route public transit data, and applying route planning to evaluated alternative trips, we aimed to reveal to what degree on-demand microtransit competes with and complements the other transit options of ride-hailing, personal car use, fixed-route public transit, and walking in the suburban environment.

All trips were evaluated for alternative fixed-route public transit routes. The results demonstrated that the trips seldom had feasible alternatives: 68% of trips had no fixed-route alternative. For those trips that had fixed-route transit alternatives, those options were generally much more time-consuming, making many seemingly unfeasible. On average, fixed-route transit alternatives took 62 min longer than their microtransit counterparts. Fig. 4 also demonstrates that microtransit was often the faster alternative. Walking did not appear to be a feasible alternative to microtransit, as microtransit was over 30 min faster than walking options in 73% of the cases.

The transit survey indicated that most microtransit riders would have mainly used ride-hailing (58%) or private cars (18%) as an alternative to their microtransit trips Fig. 5. Ride-hailing is more expensive than microtransit: a microtransit trip in the case study area is $3 or $4 whereas an Uber ride has a minimum rate of $7.49 (Uber Technologies Inc, 2022). Private car use might not be available for the entire population, in particular for low-income groups. However, microtransit was slower than private car use and, presumably, in most cases also slower than ride-hailing. On average and excluding wait time, microtransit was shown to be 1.3 times slower than private car use.

3.3. Inducing crucial trips for the transit-dependent population

By combining ridership and survey data with land use data, this section elaborates on the degree to which microtransit is enabling (vulnerable) riders to take crucial rides to their socio-economic welfare in suburban areas. The previous section showed that many of the trips taken with microtransit were previously unfeasible to transit-dependent riders. In this section, we present three more arguments demonstrating that crucial trips are being induced by microtransit.

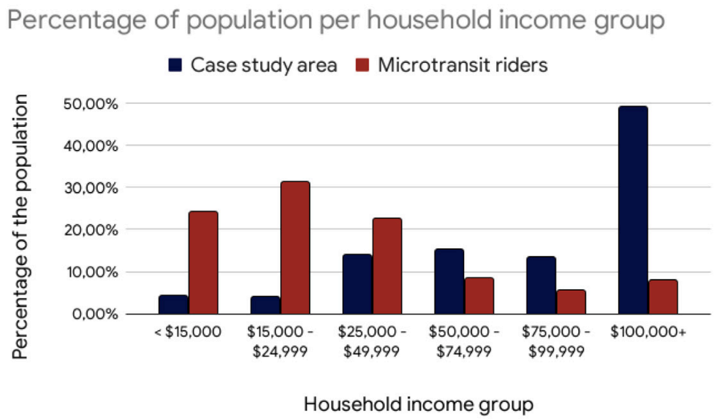
First of all, 27% of survey respondents indicated that they would not have taken their trip if microtransit had not been available. The findings suggest the availability of microtransit induced these trips. Separately, we concluded in our previous analysis that 68% of all microtransit trips did not have a fixed-route public transit alternative. This indicates that more than the originally indicated 27% of microtransit trips were induced, in particular amongst groups with low access to a vehicle. The general sense that public transit was not seen as an option for most people living in the study areas before microtransit was also reaffirmed during the interviews.

To evaluate the type of trips induced, all origins and destinations of studied rides were evaluated for aggregated land use. This resulted in two points evaluated per ride. As shown in Fig. 6, 41% of these points either originated or arrived in a residential environment. The second-largest occurring land use was retail and commercial, making up 31% of points. This suggests that microtransit was used majorly to connect residents to (commercial) points of interest. In terms of combinations of land use by far the most common combination is residential to retail and commercial, 40% of all trips form a bridge between this combination of land use types. Fig. 8 demonstrates how the spatial High-High clusters overlap with the commercial and retail centers for both studied areas. This further solidifies the idea that microtransit mainly forms a bridge between residents' homes and commercial centers.

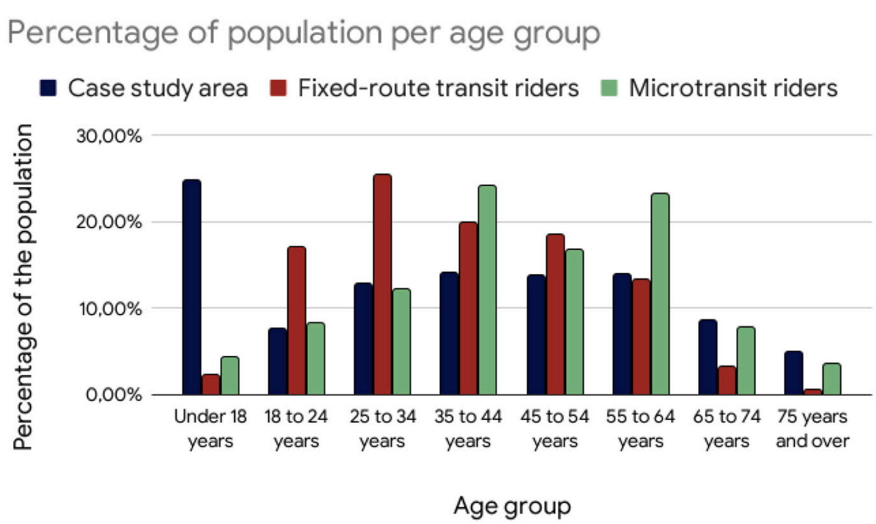
The match between residential areas and commercial land use aligned with the indicated travel purposes of survey respondents, which are shown in Fig. 7. In the survey, the most common travel purpose was work/commute (56%) and the second most common purpose was shopping (14%). Both can be coupled to retail and commercial land use, though work can be coupled to institutional, industrial, or utility land use as well. This demonstrated that microtransit is majorly used for rides that are crucial to the socio-economic well-being of riders, most prominently work.

3.4. Alleviating access inequity

Following the interpretation of Rawls' egalitarianism by Pereira et al. (2017) we have assessed the impact of microtransit on vulnerable riders in Section 3.1 and concluded that microtransit reaches several



(a) Distribution over annual household income groups for microtransit survey respondents, fixed-route transit survey respondents, and the general population of the area. The figure demonstrates that low-income groups were disproportionally represented amongst the microtransit survey respondents.



(b) Distribution over age groups for microtransit survey respondents, fixed-route transit survey respondents and the general population of the area. The figure demonstrates that microtransit riders were more regularly members of the older age groups and that microtransit reached less riders under 35 than fixed-route transit.

Fig. 3. Two graphs showcasing the distribution of income and age compared between different population groups within the case study area.

vulnerable rider groups, including elderly riders, riders with disabilities, and low-income riders. Now, we will show how microtransit reaches the spatially disadvantaged riders and how it shifts the distribution of access, following the example of Delbosc and Currie (2011) and Lucas et al. (2016). By combining data on the spatial location of amenities and jobs with trip planning software, computing access scores, and generating Lorenz curves, we estimated whether and how microtransit impacted access equity in suburban areas.

3.4.1. Shifting the distribution of access

When aggregating the three access scores to one access level, the access scores for choice riders (car owners) were found to be overall much higher than those for transit-dependent (microtransit and fixed-route transit) riders. When we focus on the transit-dependent population, access enabled by microtransit was found to be much more equally distributed compared to access enabled by fixed-route transit. Fig. 9 clearly shows the shift from an unequal pre-microtransit distribution, with Gini coefficients of 0.684 (area A) and 0.477 (area B), to a distribution that closely approximates the line of absolute equality for the post-microtransit situation.

An analysis of the Gini coefficients for individual access levels to services was conducted. This revealed that for area B, all service types showed a similar alleviation in inequality of 0.44–0.47. For area A there was more variety between service types, with a shift of the Gini spanning from 0.51–0.71. In particular the access to jobs stood out here: the distribution of access to jobs was less unequal in the pre-microtransit situation compared to the access to shops and healthcare facilities and thus showed a smaller shift in distribution. The access

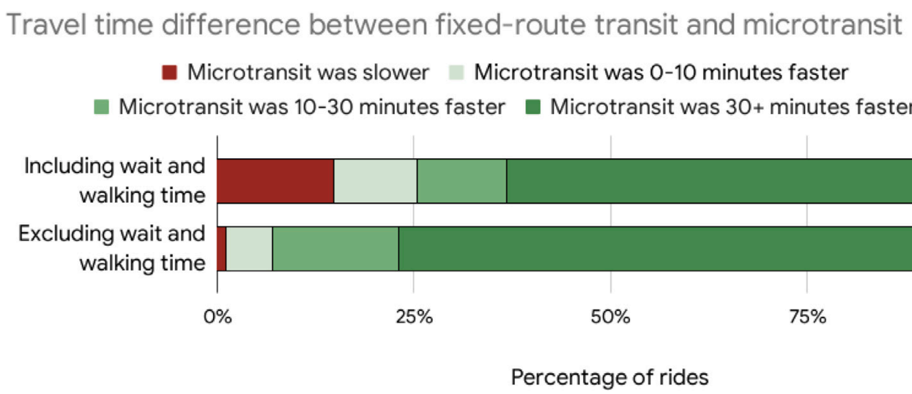


Fig. 4. The travel time difference between fixed-route transit and microtransit, demonstrating that microtransit was generally a (much) faster alternative to fixed-route public transit, in particular when the wait time is excluded.

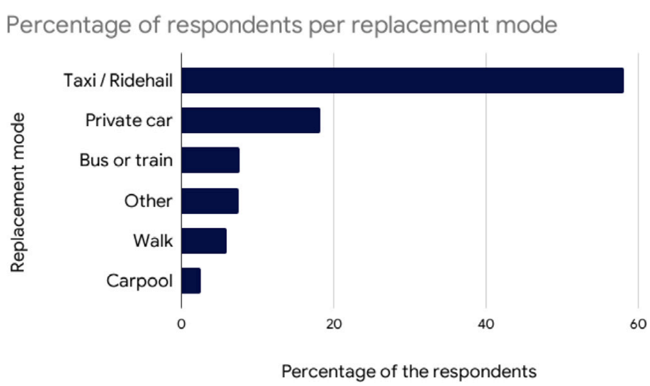


Fig. 5. The replacement mode indicated by survey respondents, ranked by most common responses, the less sustainable and more expensive alternatives ride-hailing and private car use were mentioned most often as the preferred replacement mode.

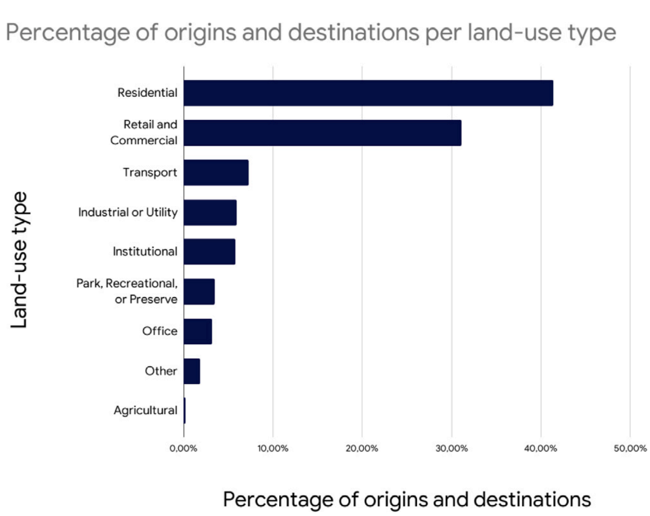


Fig. 6. The distribution of trip origins and destinations across different land use types, demonstrating residential and retail and commercial land use as being most prominently represented in the studied trips.

levels for shops showed the largest shift from pre- to post-microtransit situation and the access to jobs showed the smallest shift in both areas. Overall, the calculation of the aggregate metric does seem to represent the data well. The alleviation from pre- to post-microtransit for the individual access to services is overall similar to the aggregated shift. The scores are provided in section 4.6 of the supplementary information document.

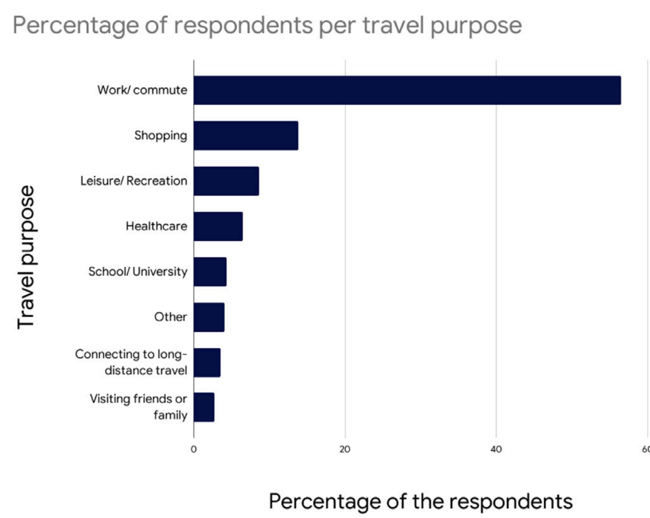


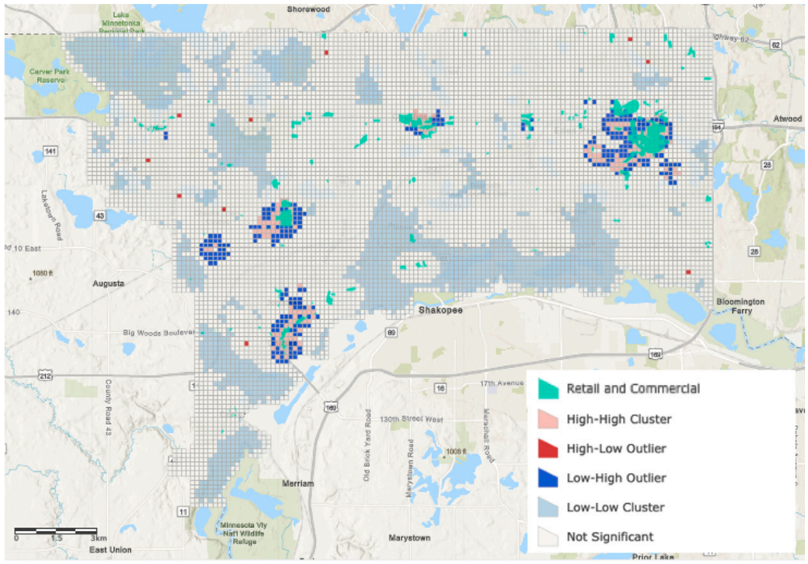
Fig. 7. The travel purposes mode indicated by survey respondents, ranked by most common responses, work/commute is represented most prominently as a trip purpose in the data set.

3.4.2. Improved spatial distribution of access

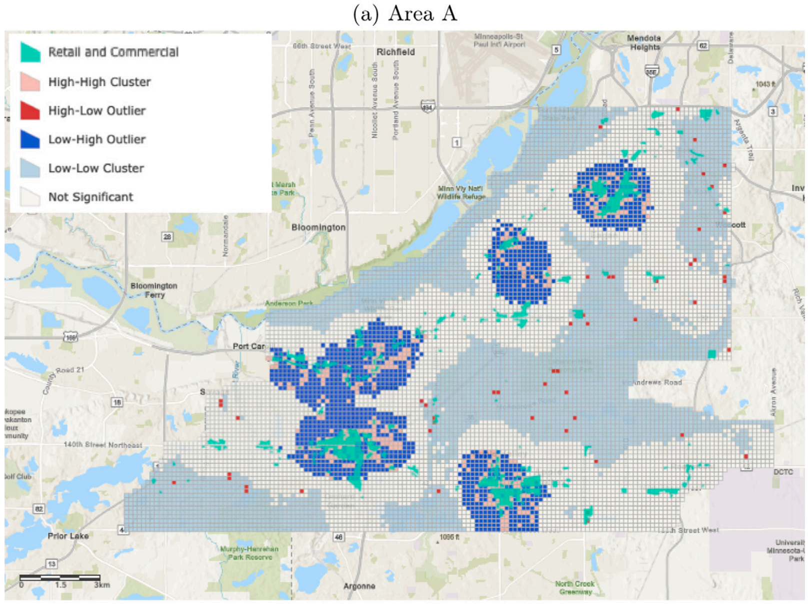
Since microtransit services could originate anywhere within the service area, the benefits of microtransit are not as spatially concentrated as the benefits of fixed-route public transit. This is also shown in Fig. 10. This figure displays the census block groups that benefited most from the introduction of microtransit. When overlapped with the locations of fixed-route transit stops, the benefit of microtransit can be observed to be highest in the areas where fixed-route transit stops did not exist. In that way, microtransit could act as an equalizer: providing benefits to those who do not have access to fixed-route public transit.

4. Discussion and conclusions

This study demonstrated that on-demand microtransit is a valuable addition to the transportation mix in suburban communities – at least in the case of Minneapolis-St Paul. In contrast to ride-hailing options, which majorly reach the young and wealthy (Rayle et al., 2016; Cats et al., 2022), microtransit reached vulnerable rider groups, namely seniors, low-income individuals, and individuals with disabilities. Microtransit thereby can fulfill the role of serving communities that have historically been marginalized from public transit. We also demonstrated that microtransit rarely competes with fixed-route public transit, and instead offers a respectively faster or less costly alternative to fixed-route transit and ride-hailing for transit-dependent riders. Our results were therefore more optimistic than those presented by Haglund



(a) Area A



(b) Area B

Fig. 8. Two outlier- and cluster analyses of the trips overlapped with retail and commercial land use areas, visualized in ArcGIS. These visualizations demonstrate that the High-High clusters overlap with the retail and commercial land use areas.

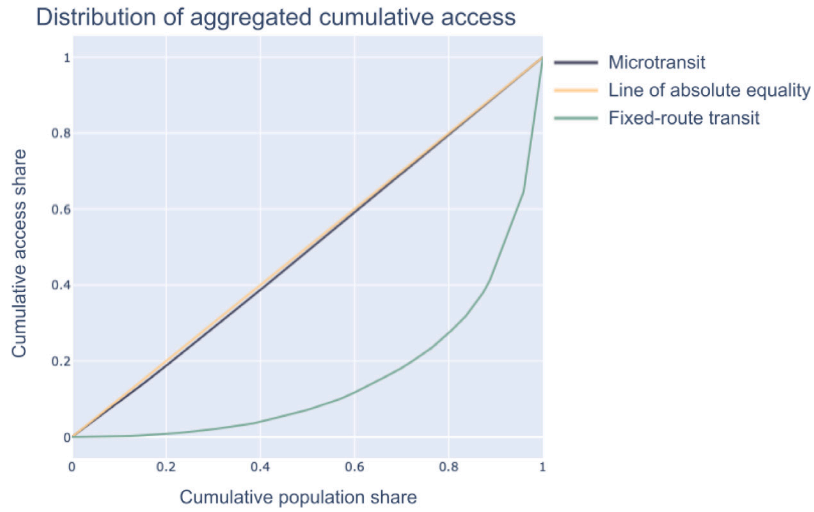
et al. (2019) in Helsinki, Finland, which suggested that microtransit regularly replaced fixed-route transit. This could be due to our study area having far fewer options for fixed-route transit and cycling than Helsinki.

On-demand microtransit enables vulnerable riders to take trips that are crucial to their socio-economic welfare. Firstly, the observed trip induction rate was high (>27%), signaling an increased activity rate of residents. Additionally, the most common travel purpose indicated by riders was work and/or commute, demonstrating that microtransit serves as a pathway to employment opportunities. Lastly, the performed spatial analysis indicated that microtransit indeed formed a bridge between residential and commercial areas, thereby enabling riders to reach places of employment as well as consumption. This demonstrates the socio-economic value that microtransit brings to individuals and workplaces in our study area.

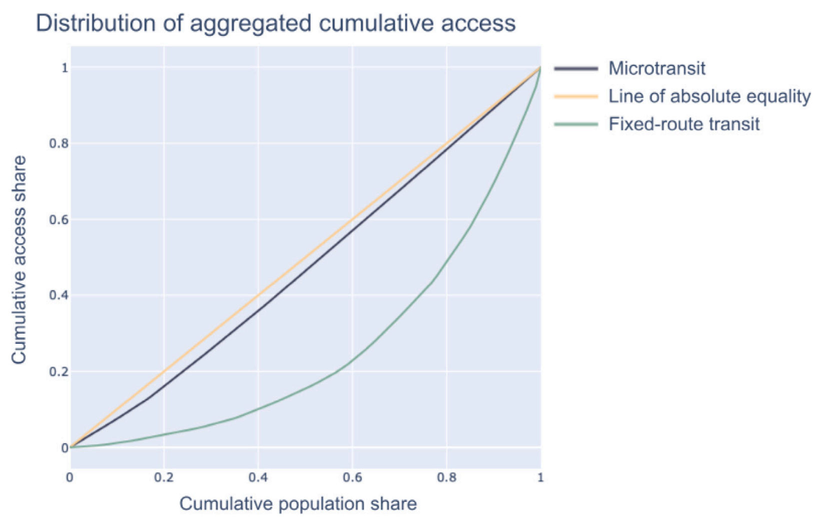
Finally, on-demand microtransit redresses transportation inequity by alleviating access inequality, reaching vulnerable rider groups effectively, and creating travel opportunities that are less spatially concentrated than those provided by fixed-route public transit. Access enabled by microtransit is very fairly distributed across the population, and most benefits are felt by those with low car ownership and residents who previously had no, or inconvenient, access to fixed-route public transit. Thus, microtransit seems to fulfill the suggestion made by Yan et al. (2022) that, in the right circumstances, microtransit can alleviate access inequity. Our study is the first to provide such evidence in a suburban context in the USA. Through this evidence, we support the addition of on-demand microtransit services to the toolbox of transit planners and policymakers aiming to alleviate access inequity in their cities.

4.1. Limitations

The methods employed in this study were limited in that the accessibility analysis focused solely on travel time, not considering monetary costs and other factors like comfort and convenience. Additionally, the cumulative accessibility measure employed in this study is generally considered less theoretically sound than the gravity-based or utility-based measures. It was still selected due to its simplicity of calculation



(a) Area A, the Gini coefficient is shifted from 0.684 to 0.016.



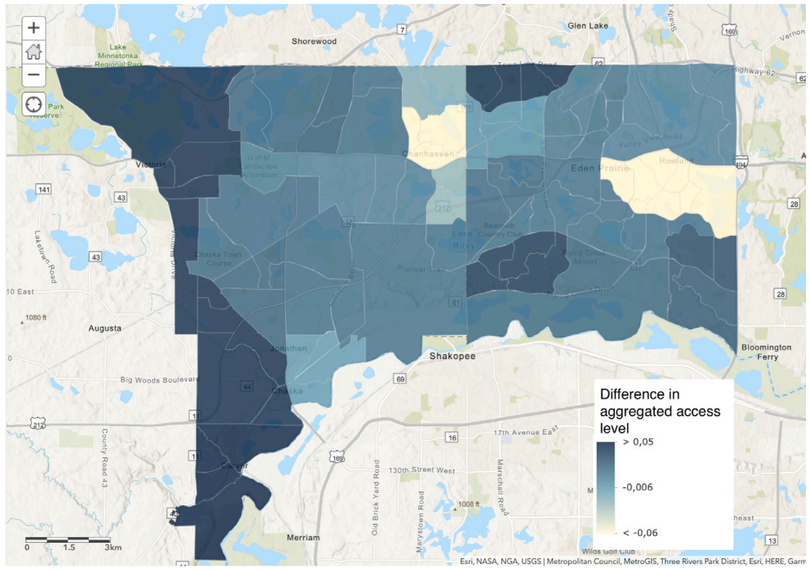
(b) Area B, the Gini coefficient is shifted from 0.477 to 0.045.

Fig. 9. The Lorenz curves showing the aggregated access distribution. For both cases, the adjustment is major and shifts the distribution of access from extremely unequal to extremely close to the lines of absolute equality.

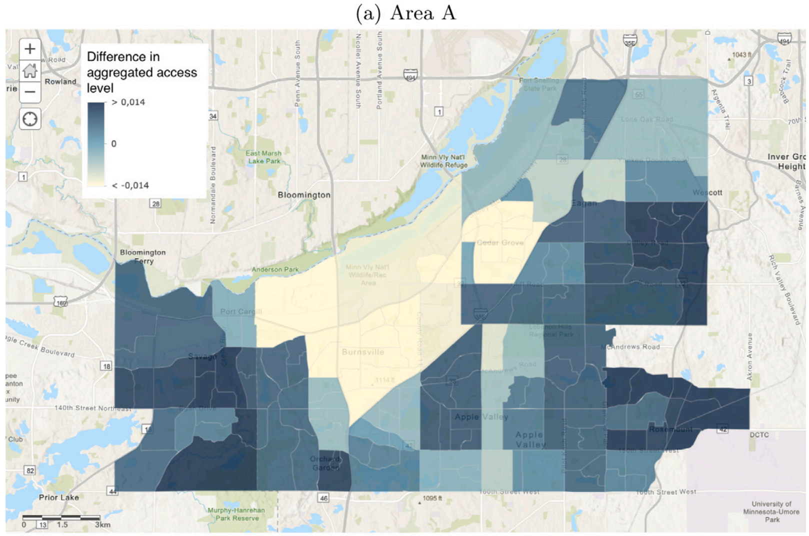
and strong communicative value (Santana Palacios and El-geneidy, 2022). Only access to jobs, shops, and healthcare facilities was considered for the accessibility analysis. A more detailed analysis including other public and critical facilities (e.g. schools, transit stations, and green space) might have resulted in more accurate and representative results. However, clear overlap exists between the location of jobs, shops, healthcare facilities, and other points of interest, mitigating the effects of leaving these points out.

Additionally, the mechanism of trip chaining, which is the combination of trip purposes and modes, was not accounted for in this analysis due to its complexity. Including trip chaining might have lowered the additional access gained by microtransit over individual car use since microtransit is still less flexible than individual car use. Simultaneously, it would have increased the benefit of microtransit over public transit, due to the much higher level of flexibility that microtransit has over fixed-route public transit. The inclusion of the combined use of microtransit with fixed-route transit, exploiting the bridging function of microtransit, might also have changed the results. However, this complex travel behavior was beyond the scope of the current study. If included, this dynamic would have improved the access levels of the transit-dependent population since combined use inherently creates more travel opportunities than the use of solely microtransit or solely fixed-route transit. Furthermore, the calculation of the level of access assumed an unrealistically high availability of microtransit services. This assumption may not align with the real world, where microtransit typically operates as a minority transportation mode, preferably complementing fixed-route transit. However, though this scenario may not be an accurate representation of reality, it provides valuable insights into the inherent equal distribution of access enabled by microtransit, which in itself is a valuable finding of this study. Thus, the employment of such a hypothetical scenario was justified. The current approach balanced scope with theoretical soundness.

Additionally, some limitations can be identified in the data sources. A combination of data sources in total spanning from 2016 up until 2022 was used. Slight differences might have occurred within that time frame and unfair matching of the data across several sources might have occurred for that reason. An attempt was done to mitigate this effect by only using data from the same year when directly matching different data sources. Besides this, it can be assumed that there is some level of consistency over this time frame when considering land use but also job availability, and infrastructure. Missing data values on wait



(a) Area A



(b) Area B

Fig. 10. The spatial distribution of the benefits of microtransit for aggregated access, calculated through subtracting the aggregated access level pre-microtransit from the aggregated access level post-microtransit. The lighter areas are concentrated around major transit corridors.

time as well as on the difference between requested and realized pick-up time were imputed with mean values. The interviews conducted with senior employees of the (micro)transit providers might be biased and leading due to them being conducted by one of the authors herself and the sample size being limited. Therefore, the conclusions drawn from the interviews were always supported by quantitative data, solidifying these findings nevertheless.

4.2. Policy implications

Based on the results of this paper, several policy recommendations can be offered to both transit providers and urban policymakers. First and foremost, when considering the implementation of microtransit, it is crucial to consider whether microtransit is an appropriate solution for the transportation challenges of a region. Our study area is suburban, has low walkability, and lacks fixed-route transit. This resulted in microtransit being able to alleviate the significant access inequality that was a reality of the existing spatially concentrated fixed-route transit network, as demonstrated in Section 3.4.2. In a more densely populated area, demand might outstretch microtransit capacity and fixed routes might be a more sustainable alternative for high levels of demand. In less densely populated areas, the microtransit option might be too inefficient. The transit providers themselves emphasized that a good fit with the use case is crucial for microtransit and that the service that the microtransit service might not work well in an urban (core) or rural environment. Thus, the feasibility and effectiveness of a microtransit system in other environments, specifically urban and rural, should be further investigated before any concrete implementations can be suggested for those types.

To maximize the positive impact of on-demand microtransit on access equity following the interpretation by Pereira et al. (2017) of Rawl's egalitarianism, we suggest the following. First, the income and car ownership levels of the community to be served should be considered. Communities with low income and car ownership, or transit-dependent individuals, should be prioritized because they gain the highest benefits from microtransit and are vulnerable transit groups, as is detailed in Sections 3.1 and 3.3. These were also the first groups targeted by the transit providers in our area of study. Other vulnerable transit groups such as senior and young riders as well as riders with disabilities should also receive specific attention in implementing microtransit systems. Microtransit already is more accessible to the physically disadvantaged through being a curb-to-curb service, which minimizes walking time.

Lastly, the integration of microtransit service with an existing local public transit agency may be an important step towards success. The advantages of this were visible during the interviews: (i) the agency already has information on which routes are and are not performing well in the current fixed-route transit system, (ii) the agency has know-how on the transit demand and demographic of the community, and (iii) dealing with a familiar transit agency might lower the barrier for vulnerable transit groups, in particular seniors, to make use of the microtransit system.

4.3. Future work

Our focus on suburban environments, which was prompted by the particular challenges around the suburbanization of poverty in the USA, was fundamental to this work. We acknowledge that it also limits the applicability of our findings to other environments. Future research on the urban access equity impact of microtransit should widen the focus to the urban core and rural environments, as well as on different countries.

Furthermore, the relationship between microtransit and fixed-route transit – and the ability of microtransit to contribute to first/last mile challenges – should be further investigated. Using microtransit to strategically connect riders with high-frequency public transit corridors could greatly boost accessibility levels. Further investigation is required to understand the specific barriers that prevent fixed-route public transit agencies from implementing this option.

Finally, the environmental impact of microtransit (e.g. air and noise pollution and greenhouse gas emissions) was considered to be outside of the scope of this study, but it is an important topic for further investigation. Microtransit can reduce traffic congestion if it replaces enough private vehicle trips, but mode shift away from fixed-route buses, cycling, and walking could lead to a larger environmental footprint under the wrong circumstances. As cities continue to grow and the number of trips within them increases, it will be crucial to ensure that microtransit plays a sustainable role in the transportation mix.

CRediT authorship contribution statement

A.M. Liezenga: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **T. Verma:** Conceptualization, Methodology, Supervision, Writing – review & editing. **J.R. Mayaud:** Conceptualization, Data curation, Methodology, Supervision, Writing – review & editing. **N.Y. Aydin:** Methodology, Supervision, Writing – review & editing. **B. van Wee:** Methodology, Supervision, Writing – review & editing.

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.

Data availability

Data and code is shared in the Supplementary Information Document. Transcript of interviews and microtransit ridership and survey data cannot be shared due to confidentiality and privacy regulations.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.trip.2024.101071.

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