Master Thesis in Engineering and Policy Analysis

Escaping Suburbia

A Case Study on Microtransit and Access Equity in the Minneapolis-St.Paul Metropolitan Area

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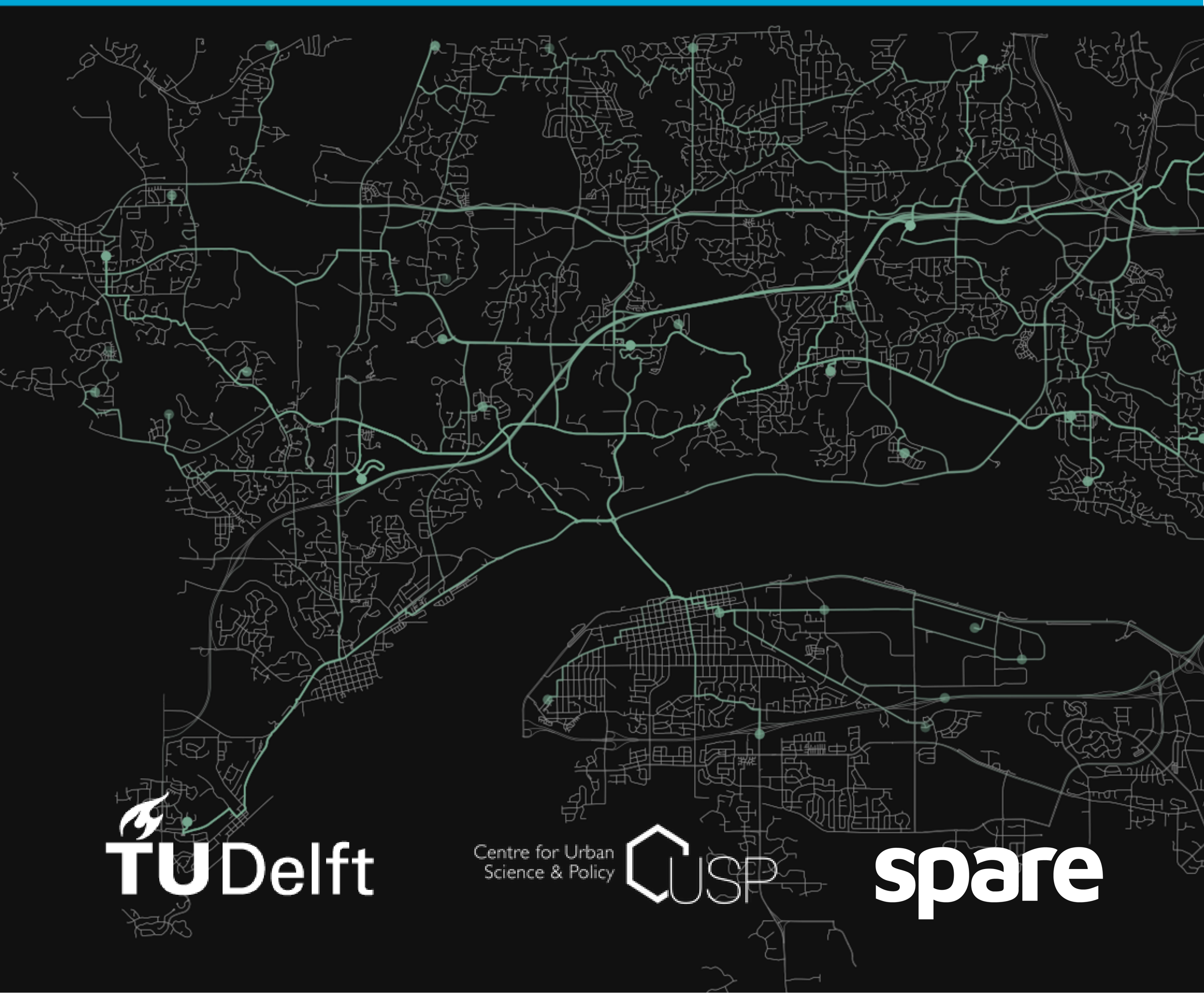

ESCAPING SUBURBIA: A CASE STUDY ON MICROTRANSIT AND ACCESS EQUITY IN THE MINNEAPOLIS-ST.PAUL METROPOLITAN AREA

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EXECUTIVE SUMMARY

More and more people are living in cities [Ritchie and Roser, 2018]. Though life in cities is attractive, it also comes with challenges: recent studies have shown that as cities grow, the benefits of living in them are increasingly unequally distributed [Heinrich Mora et al., 2021]. Cities in the U.S.A. in particular additionally face the contemporary challenge of suburbanization of poverty [Stacy et al., 2020]. To reach the Sustainable Development Goal: 'Make cities and human settlements inclusive, safe, resilient and sustainable' [United Nations, 2021] action needs to be undertaken. One factor that can turn the tide of glooming urban inequality is equitable access to opportunities [Dociu et al., 2012]. Creating policies for equitable access requires defining and considering several components of accessibility, defined by Geurs and Van Wee [2004] as (i) land-use, (ii) transportation, (iii) individual needs and opportunities, and (iv) temporal constraints.

In this research, this definition of accessibility is used to study microtransit, a shared mobility transit service that employs highly flexible routing and scheduling and for which customers can request rides using a mobile app. The rides are often, if not always, shared and (mini)buses are used more regularly than cars [Shaheen et al., 2015]. Unlike ride-hailing, this form of on-demand transit has not been studied extensively yet, though its market has grown fast in recent years [Foljanty, 2021]. Urban inequality, lack of accessibility, and the suburbanization of poverty are pressing issues. Microtransit, with its flexible and public nature, might fit this challenge well. This research will study microtransit utilizing a case study in the Minneapolis-St. Paul Southern suburbs. The aim will be to answer the following main research question: 'What are the access equity implications of microtransit services in urban environments?'

RESEARCH QUESTIONS

As stated above, the model by Geurs and Van Wee [2004] is used to answer this main research question. To clarify the different facets of the relation between microtransit and access equity, the following subquestions will be answered:

1. Which relations and components determine the access equity implications of microtransit?
2. How do the individual characteristics of (potential) riders co-determine the choice for and usage of microtransit as a mode of transport?
3. How does land-use impact the spatial distribution of microtransit trips?
4. How does microtransit as a mode of transport compare to, complement and compete with other modes?
5. How (much) can the distribution of accessibility to opportunities be shifted by the addition of microtransit as a mode of transport?

ANSWERS TO THE RESEARCH QUESTIONS

The data utilized, methods employed, and findings per research question will now be listed:

1. Inspired by the conceptual model of accessibility by Geurs and Van Wee [2004] and the academic insights discussed in Chapter 2, three conceptual models were formulated. The relation between access and microtransit is shaped by the land-use, individual and transport components. The land-use component dictates overall transit demand. The individual component co-determines which transit modes individuals can and prefer to use. The transport component determines how that transit demand can be distributed across the different transit modes, resulting in travel costs, time, and 'other' for each trip. Combined, these three components determine accessibility levels. The final step from accessibility levels to access equity is made by taking into consideration minimum levels of access as well as a prioritization of vulnerable groups. More details can be found in Chapter 3.

2. Microtransit and traditional transit survey data, as well as census data, were statistically analyzed and visualized to learn about the socio-economic and car-ownership characteristics of microtransit riders. Two interviews with senior employees of (micro)transit providers were also conducted to shed light on the history, application, and user groups of microtransit. The findings suggest that in the studied area microtransit can reach vulnerable transit groups: both low-income, non-white, elderly, and disabled individuals use the transport mode. Women and men are equally represented in the sample of survey respondents for microtransit. Through reaching these vulnerable groups microtransit fulfills the role of serving communities that traditionally struggle to use public transit. No concrete conclusions can be drawn about the relation between car ownership and microtransit usage, though the findings from the interview, repeat rates, and overall car ownership in the area do seem to suggest that microtransit is used by a smaller group of transit-dependent riders alongside a larger group of choice-riders. This can be majorly explained by the overall demographics of the area. More details can be found in Section 5.1.

3. Statistical and spatial analysis alongside findings from the interviews were used to shed light on the relationship between land-use and microtransit usage. Based on the interviews, the suburban land-use environment and its current challenges seem to fit the characteristics of microtransit well. In this environment, microtransit can fill the gap left behind by the lacking (traditional) public transit network. The suitability of microtransit to the suburban land-use environment can be caused by (i) the lack of traditional public transit services in this area, (ii) the relatively large distance between services, amenities, and residences due to urban sprawl (iii) the decrease in car ownership and income levels due to the suburbanization of poverty. The land-use analyses showed that there are significant hotspots to be identified for the microtransit rides in the studied areas and that these overlap with the retail and commercial centers. It can be observed that most trips involve residential land-use and 40% match commercial land-use to residential land-use. The fact that most trips involve residential land-use shows that most riders travel from their residence to a point of interest. In many cases, this point of interest is related to work, as is also supported by commute being the most common travel purpose indicated by survey respondents. More details can be found in Section 5.2.

4. Statistical analysis and trip planning efforts were employed to discover the competitive and collaborative (dis)advantages of microtransit compared to personal cars, public transit, walking, and ride-hailing. Microtransit offers a significant improvement in costs and travel time for the transit-dependent population. For choice-riders, microtransit can still be the preferred mode of transit because of its convenience. In the case study area, microtransit trips seldom had a feasible public transit alternative and walking counterparts of

trips were mostly unfeasible. Microtransit is slower than the modes of private car and ride-hailing but the difference is not extreme, especially when excluding wait and walking time from the equation and taking into consideration that most microtransit trips are around 15 minutes long. There is a significant potential for redistribution of cost, travel time, and 'other' through the addition of microtransit to the transit mode mix. Microtransit also induces new trips, especially for transit-dependent riders. More details can be found in Section 5.3.

5. A combination of trip planning efforts, accessibility analysis, and statistical analysis was conducted to calculate accessibility scores with and without microtransit. These scores were calculated based on the cumulative measure of access to jobs, shops, and healthcare facilities and aggregated into one access score. These analyses demonstrated that, though microtransit struggles to truly shift the distribution of access, the service can get many residents to a minimum standard of access without a car. The extent to which microtransit alleviates the existing inequality in the distribution of access in this area is limited because the car remains a much faster alternative, which can reach outside the bounds of the service area. However, the access enabled by microtransit is very fairly distributed across the population, and most benefits are felt by those with low car ownership. Spatially, those that live furthest away from transit corridors and services feel the most benefits from microtransit. Additionally, Microtransit does significantly improve the access level of those that do not have access to cars. More details can be found in Section 5.4.

DISCUSSION, CONCLUSION AND POLICY RECOMMENDATIONS

This study showed how microtransit impacts access equity through the individual, land-use, and transport component and in particular by redistributing overall access levels to jobs, shops, and healthcare facilities. This study is one of the first of its scope on the relation between microtransit and access equity and contradicts some earlier findings on the profile of shared mobility riders as well as the equity impact of microtransit. Though the study is limited by the case study approach, which makes it difficult to generalize findings, some policy recommendations can be made based on its results:

- It is crucial to carefully consider whether microtransit is the right fit for an area. The suburban environment seemed to be a good fit: the challenges of the contemporary suburbs can be partly resolved by public microtransit services because they can serve a low-income, transit-dependent demographic, don't require extensive infrastructure, and can be flexibly used. In general, the income and car-ownership level of the community as well as the interests of vulnerable transit groups should be taken into consideration when implementing a microtransit network.
- Integration of microtransit services with the existing public transit providers is a good approach: (i) this agency already has information on which routes are and are not performing well in the current public transit system, (ii) this agency also has the know-how on the transit demand and demographics of the community, and (iii) interacting with a familiar transit agency might lower the barrier for vulnerable transit groups, in particular the elderly, to make use of the microtransit system.
- The impact of the microtransit network on access equity can be tracked to some extent by (i) conducting surveys to track the average income, disability

status, race, gender, and age of riders, demonstrating the extent to which the service is reaching vulnerable riders, and (ii) microtransit trips can be sampled and analyzed with a trip planner to check travel times compared to cars, public transit, and walking alternatives, providing insights into the competitive value of microtransit as well as preventing it from replacing the more sustainable alternatives public transit and walking. These trip planning efforts can also inform service providers about their competitiveness with other transit modes.

- The two main rider groups: transit-dependent riders and choice-riders should be carefully and to some degree separately considered since they have different motivations for using microtransit.
- To reach certain vulnerable groups it is important to make the service in itself accessible, through compliance to (national) standards for transporting disabled riders and ensuring that booking of trips is easily accessible for anyone.
- Some routes of the traditional public transit network might be removed as the result of the implementation of the microtransit network. In some cases, this can be justified and result in a more effective transit network. However, microtransit is less sustainable than traditional public transit. It is therefore key to constantly balance effectiveness, sustainability, and ease of use for riders.
- Microtransit has presented itself as a deeply local service. Therefore, when expansions of the network are made, they should be targeted at areas with commercial centers (opportunities) or low car ownership (likely riders). On-demand rides to specific areas of interest, such as an airport, large mall, or popular place of employment, might be considered are also recommended.
- Agreeing on joined fares and one-day tickets which enable riders to combine the microtransit with the (traditional) public transit network is a great way to encourage the first and last mile application of microtransit and thereby increase the access levels of its riders even more.

These results provide a hopeful look at the future of microtransit and transit in suburban environments in general and give policy-makers and transit providers concrete recommendations to install equitable microtransit systems. Future research should concentrate on the application of microtransit in urban (core) and rural environments, the sustainability and traffic congestion impact of microtransit, and the cognitive barriers that individuals might experience in interacting with the microtransit system.

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ABSTRACT

More and more people are living in cities. As these cities grow, the benefits of living in them are increasingly unequally distributed. One factor that can turn the tide of glooming urban inequality is equitable access to opportunities. Designing policies for equitable access requires taking into account several components that impact accessibility: (i) land-use, (ii) transportation, (iii) individual needs and opportunities, and (iv) temporal constraints. In this research, the interaction between a novel mode of public transport, microtransit, and the first three components of accessibility is investigated. The accessibility implications of microtransit in the case study area: the Southern suburbs of the Minneapolis-St. Paul metropolitan, are assessed. It is concluded that microtransit manages to reach vulnerable rider groups and interacts with the land-use environment by pairing residential areas with commercial centers. Microtransit also interacts with other modes of transit by adding both extra demand and lowering the demand for ride-hailing and personal car use predominantly. Microtransit rarely seems to replace public transit or walking alternatives. Overall, it is found that microtransit does significantly increase accessibility levels in the case study area and especially impacts groups with low car ownership. Lastly, the benefits of microtransit are more fairly distributed than those of traditional transit in the studied area. This research demonstrates the positive access equity impact of microtransit and suggests further research into choice-riders, the application of microtransit in urban (core) and rural environments, and the interplay between public transit and microtransit, as well as policy interventions for policy-makers and transit providers.

Keywords: microtransit, on-demand transit, urban inequality, accessibility, access equity

CONTENTS

1 INTRODUCTION

This chapter introduces the problem that this thesis aims to address and the scope within which a solution to this problem is investigated. This chapter also outlines the relevance of this project, the research questions, and an overview of the remainder of this report.

1.1 PROBLEM STATEMENT

More and more people are living in cities. Whereas in 1950 barely 30% of the world's population lived in urban areas, this number is projected to approximate 70% in 2050 [Ritchie and Roser, 2018]. Humans have always been attracted to life in cities and communities, which can form hubs for innovation, wealth generation, and cultural development. But urbanization brings with it health risks, extreme poverty in slums, and racial segregation [Moore et al., 2003; Dociu et al., 2012]. One recent study found that, as cities grow, the benefits of living in them are increasingly unequally distributed [Heinrich Mora et al., 2021]. Additionally, cities in the U.S.A. face the cross-generational problems of gentrification and the suburbanization of poverty [Stacy et al., 2020]. Despite these challenges the global community, in the form of the United Nations, has agreed on the Sustainable Development Goal: 'Make cities and human settlements inclusive, safe, resilient and sustainable' as a part of their mission to let all people enjoy peace and prosperity by 2030 [United Nations, 2021]. The challenges of urbanization are both pressing and diverse in origin and call for contemporary solutions.

A vital part of inclusive, safe, resilient, and sustainable cities is accessibility. Accessibility is one of the main driving forces behind the improvement of social and economic well-being in urban environments [Dociu et al., 2012]. Accessibility can be defined in several ways but the most popular description is provided by Geurs and Van Wee [2004] who defined the conceptual model of accessibility as consisting of the (i) land-use, (ii) transportation, (iii) temporal, and (iv) individual component. Alongside this theoretical definition, several metrics exist that quantify accessibility, such as cumulative opportunity, gravity-based and utility-based measures [El-Geneidy and Levinson, 2006; Papa, 2020; Handy and Niemeier, 1997]. Though some of these measures have existed for a long time, applying them in the policy-making context has proven to be a challenge: policy-makers are often hesitant to adopt and apply the measures for urban and transit planning [Koenig, 1980; Morris et al., 1979; Geurs and Van Wee, 2004; Boisjoly and El-Geneidy, 2017]. An additional challenge for policy-makers is the difficulty in defining what an equitable distribution of access means. Recent works, such as that by Pereira et al. [2017] do provide tools on this front: combining philosophical theories of sufficientarianism and egalitarianism to set standards for equitable transit. Simultaneously, Lucas [2012] and Delbosc and Currie [2011] have proposed Lorenz curves of access as an innovative and recognizable way to communicate access. Though challenges in employing accessibility metrics in the policy-making field remain, these new tools provide hopeful guidelines for solidifying the position of access.

Within urban planning, (public) transit is one of the major tools that can be employed to alter access distribution. Vulnerable groups of the population, such as low-income individuals, are most sensitive to increasing their daily activity participation rates through transit improvements [Allen and Farber, 2020]. However, ensuring equal access to transit has proven to be a challenge. In 2019 only half of the world's urban population had convenient access to public transport [United Nations, 2021]. The swift changes in transit demand that face today's city challenge public planners and call for ways to flexibly adapt public transit [Verma et al., 2021]. To this end, recent years have offered the development and rise of new forms of shared mobility, including ride-hailing, ride-sharing, and on-demand transit [Shaheen et al., 2015]. These new services have sparked academic interest: whether they complement or compete with traditional forms of transit and whether they positively impact transit equity has been the topic of several case studies across the U.S.A. and Europe [Cats et al., 2022; Jin et al., 2019; Marquet, 2020]. Results suggest that ride-hailing regularly competes with public transit, increases traffic congestion, and insignificantly impacts transit equity [Cats et al., 2022; Jin et al., 2019]. This begs the question of whether modern shared mobility services positively impact access equity.

Microtransit is one form of shared mobility service that might impact access equity positively. Microtransit employs highly flexible routing and scheduling and can be used like Uber or Lyft, where customers can request a ride using a mobile app. An added factor is that the rides are often, if not always, shared and (mini)buses are more regularly used than cars [Shaheen et al., 2015]. The services are also often run by publicly funded transit agencies, making the services lean more towards the public side of the transit spectrum and enabling coordination with the traditional public transit network [Shaheen et al., 2015]. How microtransit fits into the current findings on ride-hailing is therefore an interesting question. There is a potential for offering a complement to (public) transit services and serving communities that do not generally have good access in cities. However, initial findings suggest that microtransit mainly serves the young and wealthy [Lazarus et al., 2021]. This begs the question: what is the real impact of microtransit on access equity?

1.2 SCOPING

This research will focus on **microtransit services** that are on-demand, feature ride-sharing, are partially or completely publicly funded, and formalized. This specific group is studied because little scientific research has been done into microtransit specifically and because some of its characteristics (public nature and ride-sharing component) would suggest a positive impact on access equity, contrarily to ride-hailing options. Foljanty [2021] tracks the development of the on-demand ride-pooling market, which is referred to as microtransit here, and lists that in 2021 there were over 450 running on-demand ride-pooling services globally that roughly fit this definition. This only included formalized service, which excludes many of the services that have most of the features of microtransit in the global South. Though these services also have a potential for greatly improving access levels they are outside of the scope of this research because, due to their informal nature, data on them is too difficult to acquire.

This research will also consider **accessibility** to shops, healthcare facilities, and jobs. Accessibility can be defined along four or five dimensions per Geurs and Van Wee [2004]: (i) the land-use component, (ii) the transportation component, (iii) the temporal component, and (iv) the individual component. In this research, (ii) will be discussed extensively as transport is the central theme of this thesis. The relation of (ii) to (i) and (iv) will also be discussed extensively while (iii) is outside of the scope of the research since it does not have a direct relation to (ii). For the evaluation and discussion of **equity** of access, a minimum standard of accessibility for all and prioritization of vulnerable groups will be taken into account [Pereira et al., 2017].

1.3 RELEVANCE

The challenges of our growing cities are pressing and the growing inequity of both wealth and accessibility needs to be properly addressed to face them. If microtransit does indeed provide a transit option that contributes to an equal distribution of access and therefore, indirectly, financial and social urban equity, it is key that this transit form is thoroughly investigated and deployed where fit. By conceptualizing and operationalizing the relation between a novel transit form and access equity this thesis can provide others with guidelines for access equity analyses in relation to transit. Though research has been conducted in the field of ride-sharing and ride-hailing, microtransit still has little grounding in the scientific work. The exact implications of microtransit for access equity remain unclear, with initial works suggesting the worrisome conclusion that this type of service currently mainly serves the young and wealthy [Lazarus et al., 2021]. This research can make a contribution to the limited body of knowledge on microtransit in general and its access equity impact in particular. Additionally,

1.4 RESEARCH QUESTIONS & OBJECTIVES

The knowledge gaps found in existing literature will be discussed in more detail in Section 2.4. Overall, the literature shows a limited knowledge on the way in which microtransit might impact access equity. There is also a limited amount of case-studies on who uses microtransit, for what purposes and within which land-use environments. The competitive and complementary value of microtransit to other modes of transit is also understudied and lastly the true access impact of microtransit has not been studied. To fill these knowledge gaps the following questions have been formulated. The main question that this research aims to answer is: 'What are the access equity implications of microtransit services in urban environments?' The following sub-questions support answering this question:

1. Which relations and components determine the access equity implications of microtransit?

2. How do the individual characteristics of (potential) riders co-determine the choice for and usage of microtransit as a mode of transport?

3. How does land-use impact the spatial distribution of microtransit trips?

4. How does microtransit as a mode of transport compare to, complement, and compete with other modes?

5. How (much) can the distribution of accessibility to opportunities be shifted by the addition of microtransit as a mode of transport?

By answering these questions this research can create several deliverables. First of all, a formalization is established of the relation between microtransit and access equity. Secondly, a clear profile is formed of the type of riders that microtransit attracts, a subject that has not been studied extensively yet. Thirdly, the link between land-use and microtransit ridership is clarified. Fourthly, a clear comparison between microtransit and other modes of transport amongst several dimensions is made. Lastly, an indication of the impact of microtransit on the distribution of access in the studied environment is made. These insights combined can create estimates of the access equity impact of microtransit. These deliverables also contribute to the research aim: to create a solid understanding of the access equity implications of microtransit services in urban environments.

1.5 CHAPTER OVERVIEW

In Chapter 2 the state-of-the-art literature on the topics of urban inequality, accessibility, transit and microtransit is discussed to formulate knowledge gaps. In Chapter 3 a conceptual model is established which applies the aforementioned model of accessibility by Geurs and Van Wee [2004] to the case of microtransit. In Chapter 4 the methods and data employed to answer the research questions is discussed. Following this Chapter 5 goes through the three relevant components: individual (Section 5.1), land-use (Section 5.2) and transport (Section 5.3). Finally, these findings are synthesized into the study of overall accessibility in Section 5.4. Once these results are established the findings can be discussed (Chapter 6), the research questions answered (Chapter 7) and policy recommendations formulated (Section 7.1).

2 AN OVERVIEW OF THE LITERATURE

In this section, the state-of-the-art literature on urban (in)equality, accessibility, transit, and shared mobility are discussed. This will lay the basis for further analysis, inform the selection of methods and data, and allow for the formulation of research (sub-)questions in Section 1.4.

The literature reviewed in this chapter was selected through a process of collecting a wide array of papers, labeling and summarising those papers and making an informed selection. This process included using specific keywords on Scopus and Google Scholar, snowballing from relevant works, and using Connected Papers to fill gaps in the review. The methods are provided in detail in Section 4.1.

2.1 URBAN INEQUALITY

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, healthcare, and culture and contribute disproportionately to national economies. However, rapid and unplanned urban growth is found to be associated with poverty and a demand for services that outstretches capacity [Moore et al., 2003]. Additionally, living in a city has been associated with exposure to health risks through air pollution, crowding, contaminated drinking water, and stress of poverty and unemployment [Moore et al., 2003]. Despite the virtues of cities, recent years can make us wonder if they are really what is best for us.

As Plato wrote in 360 B.C.: 'Any city however small, is in fact divided into two, one the city of the poor, the other of the rich.' Though it has been debated whether economic inequalities increase in urban environments, they surely become more visible in them. Liddle [2017] found that increased levels of urbanization had no effect on equality in some regions, but in others had a nonlinear effect. In these cases, urbanization initially led to more equality, while higher levels of urbanization enlarged economic and rural-urban gaps, a notion which is also supported by Heinrich Mora et al. [2021]. On the contrary, a recent study on Vietnamese cities stated that urbanization in the long term reduces inequality, for example through increased high school enrollment in urban areas Ha et al. [2019]. It is therefore unclear whether increasingly large cities have a positive or negative effect on inequality, but most studies in the Western world suggest that extremely large cities cause more inequality.

But what is the cause of this inequality? An explanation that has often been named is the skills-bias, demonstrating that larger differences in skills in cities explain larger differences in income [Wheeler, 2005]. Glaeser et al. [2009] find a similar explanation stating that skill inequality explains about one-third of urban income inequality. Urban inequality in U.S.A. cities can be evaluated through a historical lens as well. Racial segregation, car-centric culture, and gentrification have shaped the land-use and population in metropolitan areas for the last decades [Stacy et al., 2020]. Traditionally, white, high-income groups migrated to suburbs that were built with a car-centric vision, resulting in urban sprawl. Now, this group is migrating back to the urban core resulting in the displacement of low-income residents into the suburbs [Stacy et al., 2020]. The car-centric vision of the suburbs does not fit the abilities and needs of this new group of residents, who traditionally have lower car ownership. The challenge of suburbanization of poverty is a defiant one, as it increases commute time for low-income residents and creates pressure to expand public transit services to the suburbs to keep access levels up to a minimum standard [Kneebone and Berube, 2013; Stacy et al., 2020]. This is one of the reasons why it is key to study contemporary urban inequality through the lens of accessibility.

2.2 ACCESSIBILITY

The concept of accessibility first gained scientific traction in the late 1950s and has been studied extensively since. In a vital work to the field Hansen [1959] defines accessibility as 'the potential of opportunities for interaction'. More recently, Geurs and Van Wee [2004] defined accessibility as a wider term consisting of several components: (i) the land-use component, reflecting the spatial distribution of supply and demand of opportunities, (ii) the transport component, describing the transport system and all its characteristics, (iii) the temporal component, reflecting temporal constraints in supply, demand and transit opportunities, and (iv) the individual component, reflecting the needs, abilities, and opportunities of individuals [Geurs and Van Wee, 2004]. In addition, Lucas [2012] suggests (iv) the cognitive dimension considering the ability of individuals to interact with the transport system. This model of accessibility by [Geurs and Van Wee, 2004] is the most commonly used scientific conceptual model of accessibility.

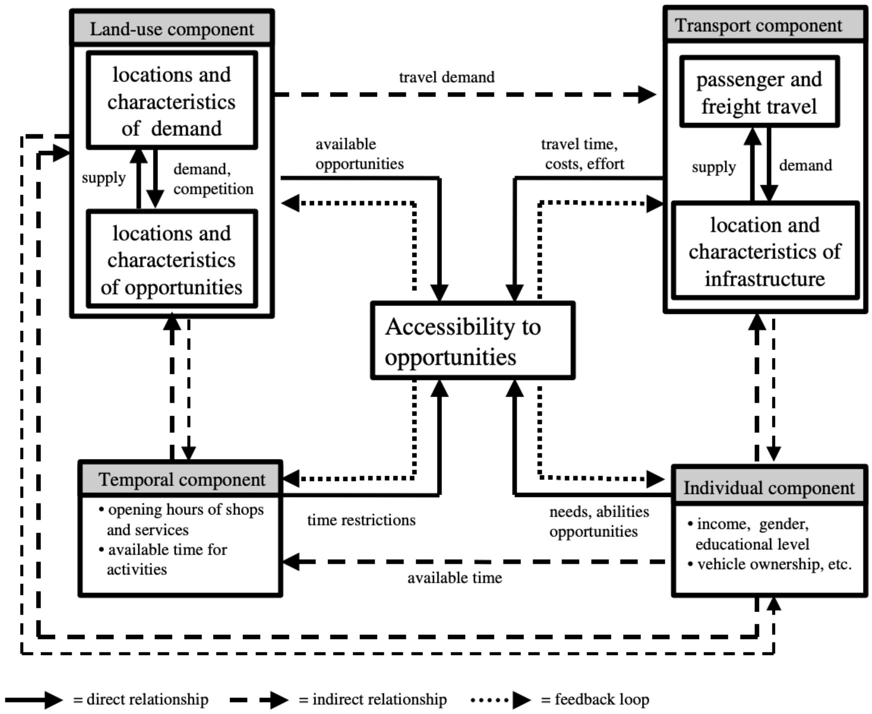


Figure 2.1: The conceptual model of accessibility by Geurs and Van Wee [2004].

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 urban and transit planning practice [Koenig, 1980; Morris et al., 1979]. A brief overview of the most crucial metrics will now be given. It is important to clarify that many more (categories of) metrics exist but that these are considered as most relevant to this study and the field in general. This list is based on El-Geneidy and Levinson [2006], Papa [2020], Stewart [2014], Handy and Niemeier [1997] and Geurs and Van Wee [2004]. The following notation is used: A_j

stands for the accessibility level of area j. O_i is the number of opportunities at location i. c_{ji} is the cost to travel form j to i, which could be defined as time, distance or monetary costs.

- **Cumulative Opportunity Measure:** (also isochronic) sums the number of opportunities that can be reached within a given travel time, cost, or distance. The advantage of this measure is that it is simple, intuitive, and easy to communicate to policymakers and planners. It is also reflective of reality to a certain degree. The drawbacks are that this measure is extremely sensitive to the selected threshold value, T (the threshold cutoff problem [Stewart, 2014]). This especially reflects poorly on the metric when considering opportunities with a concentrated spatial distribution. The measure also does not account for competition or limited opportunities.

$$A_j = \sum_{i=1}^{N} O_i * B_{ji}, B_{ji} = \begin{cases} 1 & \text{if } c_{ji} \leq T \\ 0 & \text{if } c_{ji} > T \end{cases} \tag{2.1}$$

- **Gravity-based Measure:** (also weighted cumulative opportunity or distance/-travel time decay function) sums the opportunities weighted by the travel time, distance, or cost of reaching those opportunities. The usage of the impedance function f solves the threshold cutoff problem and is still relatively intuitive, though not as communicative as the cumulative opportunity measure. The outcome is very much dependent on behavioral data to estimate appropriate decay functions.

$$A_j = \sum_{i=1}^{N} O_i f(c_{ji}) \tag{2.2}$$

  The impedance function f here can be defined in a variety of ways but is typically monotonically decreasing based on variable c_{ji}. As the cost of travel increases, the accessibility level should decrease. A regularly used form is the negative exponential.

- **Utility-based:** measures the economic benefit derived from access. It is a data-intensive and complex measure but also theoretically and empirically well-founded and reflective of the economic impact of (transit) interventions. Due to its complex implementation and the fact that the measure and its workings are more difficult to explain, it is less suitable for policy-making. In the equation below, n stands for each individual and $V_{n(c)}$ is the observable indirect utility of choice c for individual n, and C_n is the choice set for person n.

$$A_n = ln \left[\sum_{\forall \in C_n} e^{(V_{n(c)})} \right] \tag{2.3}$$

2.2.1 Accessibility for Policy-making

As shortly addressed above, the implementation of accessibility metrics for transit and urban planning requires specific attention and has been the topic of much scholarly concern. Many planners are hesitant to adopt the more mathematical, though methodologically sound, definitions of accessibility despite their proven value for policy-making [Koenig, 1980; Morris et al., 1979; Geurs and Van Wee, 2004; Boisjoly and El-Geneidy, 2017]. This might lead researchers to choose simpler and more explainable metrics, to enable a higher policy impact. This decision can at times be justified. For example, the cumulative opportunity and gravity-based measures have a demonstrated strong correlation [Palacios and El-geneidy, 2022; El-Geneidy and Levinson, 2006] 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]. Trade-offs have to be made between usability for policy analysis and theoretical soundness.

Besides this trade-off, it is also important to consider how accessibility metrics can be used as indicators of equity. Manaugh et al. [2015] in particular stressed the importance of using accessibility metrics as indicators of social equity in transport policy-making, as opposed to the local environment and congestion metrics that are now routinely used. This includes comparing the access levels of car and public transit users, of the top and bottom income quintiles, and of work and essential services trips [Manaugh et al., 2015]. As a practical implementation of measuring access equality, Lucas et al. [2016] and Delbosc and Currie [2011] evaluate access using a Lorenz curve and Gini coefficient, signifying its (un)equal distribution in a way that is recognizable to policy-makers. These works pave the way for including the equal distribution of accessibility in our evaluation of transit policies [Lucas et al., 2016; Rietveld et al., 2007; Van Wee and Geurs, 2011; Manaugh et al., 2015].

Along with the challenge of communicating equity comes the challenge of defining what exactly equity entails in a transit environment. Even if we can determine accessibility levels, policy-makers have differing opinions on what is a fair and equitable distribution of access. One work by Pereira et al. [2017] combined Rawls' egalitarianism and Capability Approaches theories, arguing that distributive justice concerns over transport should focus on accessibility as a human capability. For the evaluation of the distributional effects of transport policies this entails that (i) a minimum standard of accessibility should be taken into account and (ii) a transport policy should reduce inequality of opportunity and therefore prioritize vulnerable groups [Pereira et al., 2017]. This minimum standard of access ties in with the theory of sufficientarianism. This theory of distributive justice is concerned with the objective that everyone has enough. In terms of access, this could be defined as standards for distance to a hospital, or grocery store [Gosseries, 2011]. This combination of sufficientarianism and egalitarianism can be employed as an actionable theory of equitable transit and access distribution.

2.3 TRANSIT

Alongside and in close relation with the concept of accessibility, the concept of transit accessibility, or access to transit, exists. The concept of transit accessibility could be seen as a sub-type of accessibility where transit is not a means to enable access but a point of interest (or opportunity) in itself. In 2019 only half of the world's urban population had convenient access to public transit [United Nations, 2021]. The equitable distribution of transit is challenged even more by the contemporary swift changes in transit demand [Verma et al., 2021]. Though the concept of transit accessibility is an interesting one that holds many relations to accessibility in general, transit will be considered as a means instead of an end in this project.

Public transit will be considered now as a method of transporting the population from their homes (or other origin points) to places of interest, such as locations of jobs, shops, and healthcare facilities. Public transit in the U.S.A. in particular has long had the key function of providing accessibility for low-wage earners to their place of employment [Yan et al., 2022]. Allen and Farber [2020] suggest that neighborhoods with a high concentration of low-income and zero-car households located outside of major transit corridors are the most sensitive to improvements in accessibility increasing their daily activity participation rates. A recent study by Yan et al. [2022] in the Miami-Dade county showed great disparities in job accessibility for car users versus transit riders. Car users were able to access eight times more low-wage jobs than transit riders [Yan et al., 2022]. Simultaneously, low-income and socially disadvantaged groups are most likely to be transit-dependent [Denmark, 1998]. These problems are even more worrisome because of the aforementioned suburbanization of poverty [Stacy et al., 2020]. [Denmark, 1998] lists additional vulnerable transit groups, whom they consider 'outsiders': the disabled, minorities, and elderly. Overall, it is evident that public transit is crucial to the livelihoods and quality of life of low-income and transit-dependent riders. The lack of efficient and convenient public transit in many places around the world is therefore worrisome.

2.3.1 Innovative Modes

When existing public transit is falling behind, new and innovative modes of transit might be necessary. In recent years innovative transit services have entered the market. One major example of this is the rise of shared mobility, which has made ride-hailing and ride-sharing available to a wide public. The general rise of ride-sharing could be seen in the wider scope of the sharing economy, in which people make use of other's goods to alleviate fixed ownership burdens such as costs and environmental impact [Jin et al., 2018; Shaheen et al., 2020]. In practice, many will recognize shared mobility in the ride-hailing services Uber and Lyft and bike-sharing services such as Donkey Republic. To discuss these new concepts it is important to demarcate what they mean and how they relate to one another. Shaheen et al. [2020] has done some key work to define the field of shared mobility, with the main distinctions in service types being:

- Sharing of a vehicle: renting out cars, scooters, or bikes to alleviate the burden of fixed ownership.
- Sharing of a delivery ride: for-hire delivery services using an online application or platform.
- Sharing of a personal ride
  - Ridesharing: acquaintance-, organization or ad hoc based sharing of rides among riders with similar origin-destination pairs
  - On-demand ride services: ride-hailing of trips in a variety of forms, such as ride-splitting, ride-sourcing, and e-hailing.
  - Microtransit: (semi-)public, demand-driven transport enhanced with technology, which can incorporate flexible routing and flexible scheduling. Rides are mostly, if not always, shared, and the service often involves minibusses instead of cars.

It can sometimes be difficult to distinguish between on-demand ride services and microtransit and the terms are used interchangeably by some. This research will only cover microtransit and define it as a mode of transit that involves a driver and vehicle owned by a (public) organization, ride-sharing rather than ride-hailing, and a formal nature. Microtransit as described above was named as one of the options to improve transit for job accessibility listed by Yan et al. [2022].

Different types of shared transit do have distinct impacts on riders. Marquet [2020] examined the relation of ride-hailing to key socio-economic and built environment characteristics in the city of Chicago. The findings suggest the worrisome conclusion that ride-hailing is seldom used in the more deprived areas. Ride-hailing also seems to be predominantly used to travel between highly accessible areas which should be accessed using more sustainable transport modes [Marquet, 2020]. Additionally, Cats et al. [2022] suggests that Uber services both complement and compete with public transit by offering higher fares for a reduced travel time, thereby mainly appealing to a high-income audience. Likewise, a study in Boston found that over two out of five passengers would have taken public transit, biked, or walked if they were not to have used ride-hailing, which are undeniably more sustainable modes [Gehrke et al., 2019]. Jin et al. [2019] do recognize the potential of Uber complementing public transit in places with insufficient public transit services. However, they also find that the distribution of Uber's services is highly unequal and Uber's role in improving transport equity is insignificant Jin et al. [2019]. Rayle et al. [2016] analyzed ride-hailing users in San Francisco, finding that users were generally younger and more highly educated than the general population of the area. Overall, these works show that ride-hailing has a questionable impact on the transit mix: it is often used by younger and wealthier riders who regularly use it to replace more sustainable modes of transit.

Though microtransit and ride-hailing are similar in some regards, they have distinct characteristics that might completely change their impacts on riders and equality. Focusing more precisely on the body of work on microtransit Haglund et al. [2019] evaluated a microtransit pilot in the Helsinki capital region. Results indicated that the service had a similar hourly demand pattern as fixed public transport and the spatial distribution of trips concentrated around business-related areas. Most of the users were 30 to 63 and age dictated travel patterns. For the most part, this service replaced the car, but in some cases, it also replaced walking and cycling [Haglund et al., 2019]. Palm et al. [2021] surveyed pilots with new mobility technologies, including microtransit, in multiple countries to identify social equity impacts. They concluded that several of these technologies have the potential to improve the social equity of transit systems but failed to find any explicit equity potential of microtransit [Palm et al., 2021]. A recent work by Lazarus et al. [2021] investigated the potential of microtransit and showcased the widespread growth of microtransit services, specifically in the U.S.A., and investigated what audience microtransit attracts. This travel profile was demonstrated to be very diverse across the different regions that were studied, reflecting local differences in the availability of public transit and shared mobility services. However, active users of ride-sharing services, which are more similar to microtransit than ride-hailing, were overall younger and wealthier than non-users [Lazarus et al., 2021]. Overall, literature on microtransit's impact on access and equality is still limited and inconclusive.

2.4 KNOWLEDGE GAPS

Numerous knowledge gaps have been identified through this review of literature:

- Though there has been speculation about how microtransit might impact access equity, no quantitative data has been used to study this subject extensively yet. It is therefore unclear what the actual implications of microtransit services for access equity are.

- Though surveys of microtransit riders have been conducted and studied in the literature, the academic knowledge on user groups for microtransit is limited.

- There are also only a few sources of information on how the microtransit service connects different land-use types and how the service is spatially distributed across areas.

- The competitive advantages, disadvantages, and complementary value of microtransit services has not yet been conducted.

These knowledge gaps will be addressed using the tools, partly provided in this literature review, to answer the research questions listed in Section 1.4.

3 CONCEPTUALIZATION

In this section, the conceptual model that describes the relation between microtransit and access (equity) is presented. This lays the foundation for the relation and concepts that will be investigated in the remainder of this thesis. The research question that will be answered in this chapter is: 'Which relations and components determine the access equity implications of microtransit?'

3.1 THE ACCESSIBILITY MODEL

Figure 3.1 reiterates the model by Geurs and Van Wee [2004] applied to the case for microtransit. Since microtransit is a part of the transport component of this model, this component and its relations to the other components will be emphasized. The temporal component and its relations to other components are not further investigated. To signify this, these relations are depicted by dashed lines. The components and relations that are discussed in detail are depicted with colored blocks and filled lines. The individual and land-use components are considered as a given and the transport component is evaluated as a policy instrument.

As mentioned in Chapter 2, the individual component reflects the needs, abilities, and opportunities of individuals. In this case, the individual component is studied by evaluating a set of socio-economic characteristics and the car ownership level of the population. The land-use component reflects the spatial distribution of supply and demand of opportunities. In this case, the focus in terms of demand is on jobs, shops, and healthcare facilities. The transport component describes the transport system and its characteristics. In this case, this is quantified by the infrastructure and public transit system data in combination with estimations of the options for the microtransit network.

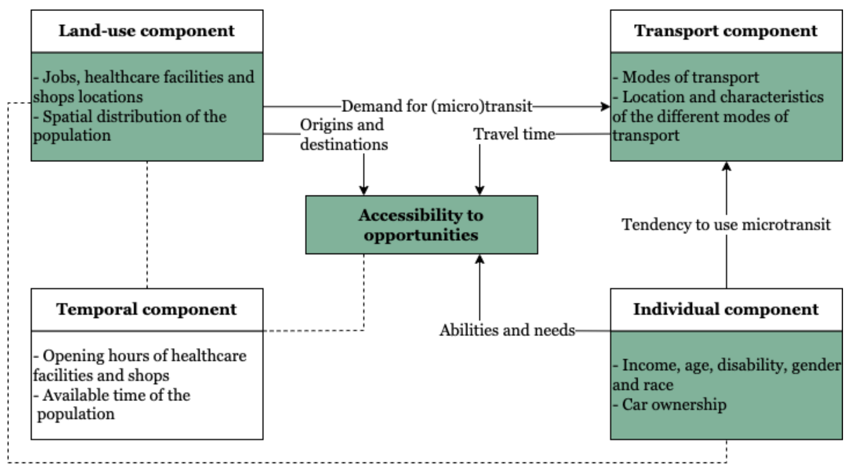


Figure 3.1: The model of accessibility applied to the microtransit case, adjusted from Geurs and Van Wee [2004]. Green components and filled line relations are studied in this thesis, broken lines and white components are not studied.

The relations between these components and the general level of access will now be shortly addressed. A more elaborate discussion of these relations will follow in the coming chapters.

- Individual - Transport: the individual characteristics of (potential) riders impact the transport component through the tendency to use specific transit modes. This tendency includes the ability to use, or not use, certain modes and the considerations that different groups might take into account different factors to differing extends for the mode choice. For example, users with no access to a car have to remove that option from their list of potential transit modes. This causes them to potentially have higher costs and also to be more likely to consider microtransit as an option (Section 5.1).

- Land-use - Transport: the land-use characteristics of an area impact the transport component through the demand for (micro)transit. The land-use provides both origins and destinations for travel, which gives the overall demand for transit. For example, areas with a high number of jobs and shops are more likely to be destinations for transit riders and therefore have a higher demand for rides (Section 5.2).

- Accessibility - Transport: in this study, the transport component impacts the overall accessibility to opportunities through travel time. The options for transport modes in an area dictate the costs and travel time for origin-destination pairs, which determine the level of access. The accessibility level is also co-determined by the land-use component, which provides origins and destinations for travel, and by the individual component, which through the individual abilities and needs determines which transit modes are available to individuals in the service area (Section 5.4).

3.2 THE TRANSPORT COMPONENT

Since the transport component is the central component of this analysis, its internal relations are shown in Figure 3.2 and elaborated on here. This model visualizes how microtransit is an addition to the range of transit options that can answer transit demand (given by the land-use component). As a new mode, microtransit can both result in answering more of the transit demand (induced trips) as well as take over demand from other modes. Which transit mode an individual selects is determined by the Generalized Transport Cost Function (GTCF), which takes costs, travel time, and 'other' as input to decide on a preferred transit mode.

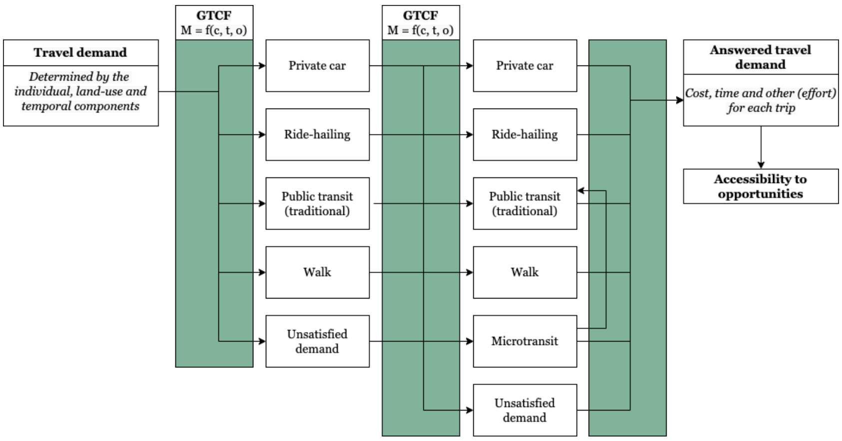


Figure 3.2: The conceptual internal model of the transport component as conceptualised in this thesis. GTCF stands for generalized transport cost function.

Shifting demand from other transit modes to microtransit can have positive as well as negative effects. It can be positive when it significantly lowers the cost or travel time for riders, which enables their level of access to increase. However, when it is used as a replacement for more sustainable modes, like public transit or walking, without a significant time or cost improvement, that might be considered a negative development. The impact of the variable 'other' is more difficult to quantify here. This factor can relate to reliability, comfort, and safety of transit modes, but also to any other factor that might be deemed relevant in the transit mode choice. It can be difficult to quantify this factor and to which extent it contributes to the choice of travel mode.

A distinct relation is also drawn between microtransit and public transit. It is regularly suggested that microtransit can solve the 'first and last mile' problem. This problem poses that the first and/or last mile to a transit station prevents the population from making use of the public transit system. A logical use case for microtransit is to be used in conjunction with the traditional public transit network to mitigate this first and last mile problem. It is also one of the potential use cases mentioned by microtransit service providers (Appendix B), though it was also expressed that the actual application of this seems limited. In the model, this creates an additional relation from microtransit to public transit where the utilized demand from microtransit can also add demand to public transit.

3.3 FROM ACCESSIBILITY TO ACCESS EQUITY

Lastly, the accessibility to opportunities can be linked to actual access equity following the considerations for distributive justice and equity by Pereira et al. [2017]. To this end, Figure 3.3 shows how the accessibility levels of a population can be evaluated using a minimum standard for access, the principle of sufficientarianism, and consideration of vulnerable groups (like low-income or low-car-ownership groups) to come to an indication of access equity.

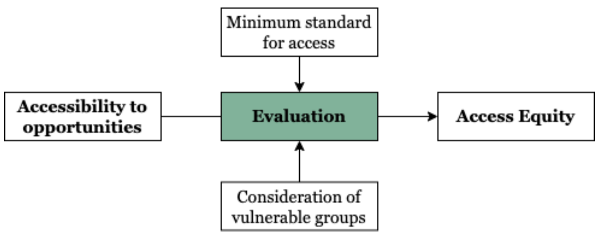


Figure 3.3: The conceptual relation between accessibility to opportunities and access equity as conceptualised in this thesis.

3.4 SUMMARY

As shown in figure Figure 3.1 the relation between access and microtransit is shaped by the land-use, individual, and transport components. The land-use component dictates overall transit demand. The individual component co-determines which transit modes individuals can and prefer to use. The transport component (elaborated on in Figure 3.2) determines how that transit demand can be distributed across the different transit modes, determined by and then redistributing travel costs, time, and 'other'. The final step from accessibility level to access equity is made by taking into consideration minimum levels of access as well as a prioritization of vulnerable groups.

4 METHODOLOGY

This section will outline the methods employed to answer the research questions proposed in Section 1.4. A mixed-methods case study approach was taken. Unstructured interviews were conducted and several types of analysis tools were applied to a variety of data. The research questions that the different methods aimed to answer will be mentioned throughout the chapter. As mentioned in Chapter 3 the first sub-question was answered through conceptual modeling.

4.1 LITERATURE REVIEW

To conduct the literature review in Chapter 2 the results of several relevant search terms on the engines Scopus and Google Scholar were systematically analyzed. Table 4.1 summarises the keywords used per section of the literature review. The works were filtered by selecting highly-cited (50+) works for older (published in or before 2015) and more general articles. For very specific and recent works the standards were lowered in this regard and the publishing journal's or university's reputation was taken into consideration to decide if the work was credible. After the initial searches, 'snowballing' was applied by looking at the references of highly relevant works. For the most relevant works and topics, the website Connected Papers was also used to check if any crucial works to the field were missing from the selection. After collecting a wide array of papers these were summarised and annotated with their key themes. A final selection based on this overview was made based on relevance, novelty, quality, and accreditation of research.

Section	**Keywords**
Urban inequality	urbanization, urbanization effects, urbanization impact equality, cities inequality, urban inequality, inequality, inequity, social inequality, economic inequality
Accessibility	accessibility, accessibility metrics, accessibility measures, urban accessibility measures/metrics, transit/transport accessibility,
Transit	microtransit, on-demand microtransit, demand-responsive transportation , ride-hailing vs ride-sharing (private ride-hailing or ride-sharing), ride-sourcing, shared mobility, public transport

Table 4.1: Keywords used per section of Chapter 2

4.2 CASE STUDY APPROACH

A case study was conducted in the Southern suburbs of the Minneapolis-St.Paul metropolitan area, shown in Figure 4.1. An advantage of the case study approach is that it links theoretical findings to real-life data, making it easier to interpret what the findings imply for urban life. A disadvantage is that it can be hard to generalize findings from one case study to general theory. The case study approach was used to answer questions 2-5.

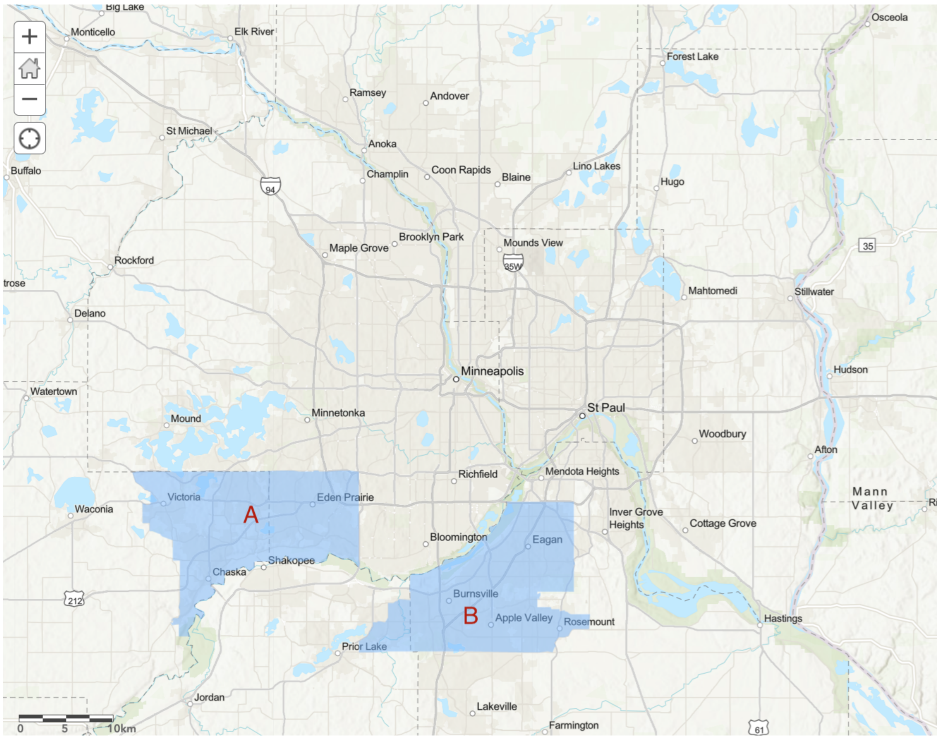


Figure 4.1: The case study area of the metropolitan area of Minneapolis-St.Paul, Minnesota, U.S.A. The service area of provider A is depicted to the left, the service area of provider B is depicted to the right.

4.2.1 Case Study Selection

Numerous case study options were available for this research. An initial list of available cities was made based on the customers of the collaborating party, Spare Labs Inc. (henceforth Spare). Spare is an on-demand transit technology provider. They are the third-largest provider of this type and have over 60 customers spread across all six inhabited continents, but predominantly in Northern America [Foljanty, 2021; Spare Labs, 2022]. The initial list consisted of 21 cities that have operational microtransit services of differing sizes. The entire list of potential cases can be found in Appendix C and consisted of cities in Canada, Germany, Norway, Spain, and the U.S.A.

An initial decision was made to focus on U.S.A. cities because of two reasons: (i) the lack of fine-grained, high-quality, and publicly available data available on both the location of services, amenities, and employment opportunities and socio-economic indicators for Canada, Spain, and Germany, and (ii) the limited size of the microtransit networks and cities in Norway. A second selection out of the thirteen potential cases in the U.S.A. was made based on: (i) past participation in the bi-annual microtransit survey, (ii) population size of the service area being at least 250 000 to ensure a focus on larger urban environments, (iii) a well-established and extensive microtransit network, and (iv) regularly updated and freely available traditional transit data, scrapping one more.

This left four potential options, of which two had service areas in the Minneapolis-St. Paul metropolitan area. This provided an opportunity to analyze and to some extent compare two service providers close to one another. The Minneapolis-St. Paul area also is a clear metropolitan area, with several municipalities forming one agglomeration. The entire metropolitan area is referred to as consisting of 7 counties, including urban core, suburban and rural areas. The studied areas (A and B) are shown in Figure 4.1.

The studied area is overall a suburban one that is relatively affluent, has high car ownership levels, and differing but overall low level of public transit availability. The service area of provider A has a smaller population than area B, even though the size of the area is similar. Area A also has a slightly higher level of car ownership than B and the (traditional) public transit system in A is much more limited than that in B, though both have a lacking transit system (this is also shown in Figure 5.18). A numerical comparison of the two service areas can be found in Appendix C.

4.3 SEMI-STRUCTURED INTERVIEWS

Two semi-structured interviews were conducted to further grasp the history, position, and motivation of the microtransit network in the case study area. These interviews were conducted with senior employees of the agencies that provide the microtransit services to the case study areas. A semi-structured form was selected to gather a large volume of qualitative information from this small sample. The semi-structured form enabled the interviewer to ask follow-up questions, and the interviewees to freely bring in their points of view and elaborate on their ideas. A disadvantage of this type of qualitative research method is that it may create interviewer as well as respondent bias [Halperin and Heath, 2020]. The semi-structured format also makes findings harder to compare and generalize [Halperin and Heath, 2020]. This drawback was taken into consideration beforehand while formulating questions and afterward while processing the interview findings into this thesis.

The interview had the following format: the interviewer gave a short presentation (5-8 minutes) on the research and its initial findings. After this, the interviewees were allowed to ask questions about the presentation and research. Hereafter 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 details, including prepared questions and presentation, and a summary of these interviews can be found in Appendix B.

After the interviews were conducted they were transcribed. The following steps were conducted to analyze the interviews: data reduction, coding, and analysis, in accordance with the guide by [Halperin and Heath, 2020]. Reduction of the data meant that all but the most interesting statements were discarded. This included reading the transcripts several times while looking for similarities, differences, and thematic connections. For example, the subtopics of transit dependence, the suburban environment, and the first and last mile problem were mentioned in both interviews by the interviewees but not by the interviewer. Through this process, the summaries provided in Appendix B were also created. As part of the coding phase, the insights were categorized based on themes, such as the history of the service, interaction with traditional public transit, and user groups. The categorized and summarised findings of the interviews were processed in the results of this thesis.

4.4 DATA PREPARATION

In this section, an overview of the data requirements is given and operationalization and cleaning are described.

4.4.1 Requirements

The following data types from the case study area were necessary to answer the research questions:

- Microtransit Survey data to evaluate the characteristics, preferences, and travel purposes of microtransit riders.
- Microtransit Ridership data to investigate the origins, destinations, and travel time of microtransit rides.
- Traditional transit survey data to evaluate the characteristics, preferences, and travel purposes of traditional transit riders.
- Traditional transit routing information to compare the hotspots and available routes of microtransit with traditional transit.
- Urban spatial data on socio-economic indicators of citizens to compare the socio-economic profile of microtransit riders to the general socio-economic profile of the area and to estimate the impact of microtransit interventions and (lack of) accessibility.
- Urban spatial data on the availability and location of services, amenities, and employment opportunities to evaluate travel purposes and set hypothetical travel destinations.
- Urban spatial data on land-use to analyze the relation between ride origin and destinations and land-use.
- Urban spatial data on (road) infrastructure to analyze travel time and network characteristics.

4.4.2 Operationalization

The required data types mentioned above were operationalized as follows. Exact queries and data set sizes are given in Appendix C.

- Microtransit Survey data was extracted from Spare's database. This survey was deployed bi-annually to all microtransit riders via SMS and matched to a trip record. Around 1200 data points from four rounds of surveys in October/November 2020, April/May/June 2021, November 2021, and April 2022 were analyzed. The exact questions and potential answers can be found in Appendix C. This data includes information on the purpose of the user's transit, age, gender, ethnicity, and annual household income. This data provided a very rich source of information on socio-economic indicators of riders and insights into the motivation for using microtranist.
- Microtransit Ridership data were also extracted from Spare's database. This data featured origin and destination latitude and longitude up to a precision of 5 digits (e.g. -94.562), equivalent to an accuracy of 78.7 meters at the 45 N/S, where neighborhoods and streets can be recognized unambiguously. The user ID was removed from this dataset due to privacy regulations. Over 200 0000 trips were recorded from the period August 2019 till April 2022. In major lines, the following steps were taken to clean this data: unrealistically long rides (in time or distance), rides that were conducted outside of the service area, and trips that were not completed were removed.
- Traditional transit survey data was extracted from the Travel Behavior Inventory (TBI) Fall 2016 Transit On Board Survey conducted by the Metropolitan Council. It should be noted that this is the most recent dataset available on this scale, though changes in travel patterns due to, e.g. the covid-19 pandemic, should be taken into consideration during the analysis of this data [Metropolitan Council, 2017].

- Traditional transit routing information was predominantly found 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 updates GTFS files could be found on Transit.land [Interland Technologies, 2022].

- Urban spatial data on socio-economic indicators of citizens were found in several Census data, a full overview of the data used can be found in Appendix C. The Census data set is a high-quality and fine-grained data set counting every person living in the U.S.A. and uncovering many socio-economic indicators, the most recent data is from 2020 [United States Census Bureau, 2022].

- Urban spatial data on the availability and location of services, amenities, and employment opportunities:
  - A major source for this data was OpenStreetMap (OSM). OSM is a community-driven source of GIS data on roads and amenities [OpenStreetMap, 2022]. This resource is available worldwide though its quality can differ per location. The locations of shops and healthcare facilities were extracted using the Overpass-turbo wizard [Nominatim, 2022] and the keywords given in Section C.6. These keywords might be prone to bias and the OSM data might be outdated or missing some locations.
  - For the employment data an altered version of the LEHD-LODES data was used [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 Minneapolis-St.Paul area. This was slightly older (2019) and the data does not include informal work. However, the general zones with high levels of employment opportunities are assumed to be overall consistent over time and formal/informal work.

- Urban spatial data on 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 something that (on an aggregated level) does not radically change over time.

- Urban spatial data on (road) infrastructure was downloaded in the form of OpenStreetMaps files, which were extracted using BBBike [Schneider, 2022]. Three extracts were made for differing purposes: two smaller ones of only the services areas themselves and one larger of the entire metropolitan 7-county area. This was done to increase computational efficiency and did not seem to cause a problem because the fastest route between the two studied points is typically within the scope of the studied area.

4.5 RESEARCH FLOW DIAGRAM

The flows between the data (quantitative and qualitative) and answers to the research questions are clarified in Figure 4.2. An extended version of this diagram which also displays the methods that were used to go from data to results is shown in Appendix A. The diagram summarises the data detailed in Section 4.4.2 as ridership data: microtransit and traditional transit survey and ridership data, socio-economic data, points of interest, and land-use data: urban spatial data on the availability of jobs, shops, and jobs and land-use, and infrastructure data: traditional transit routing information (GTFS) and urban spatial data on road insfrastructure (OSM). The semi-structured interviews are listed as a type of qualitative data.

The qualitative data is used to answer research questions 2 and 3 in particular while all research questions make use of (a selection of) the quantitative data sources. Which exact data source is used per research question is shown in Appendix A. Each research question also has several subcomponents that combined comprise that specific component. For example, to find the access impact of microtransit cumulative access to jobs, shops, and healthcare facilities is calculated, from which aggregated access scores can be established for 3 different scenarios. From these scores, the spatial and socio-economic distribution of access can be estimated and analyzed. Combined these 3 analyses answer research question 5: 'How (much) can the distribution of accessibility to opportunities be shifted by the addition of microtransit as a mode of transport?'. This answer in itself highly contributes to answering the main research question: 'What are the access equity implications of microtransit services in suburban environments?' since it sheds light on the operationalized access and its distribution.

The other three research questions and subparts all illuminate one of the components of the conceptual model of accessibility, emphasized in Chapter 3 and therefore contribute to a clear view of one of these components. In this way, they can contribute to access equity impact estimation and conclusions.

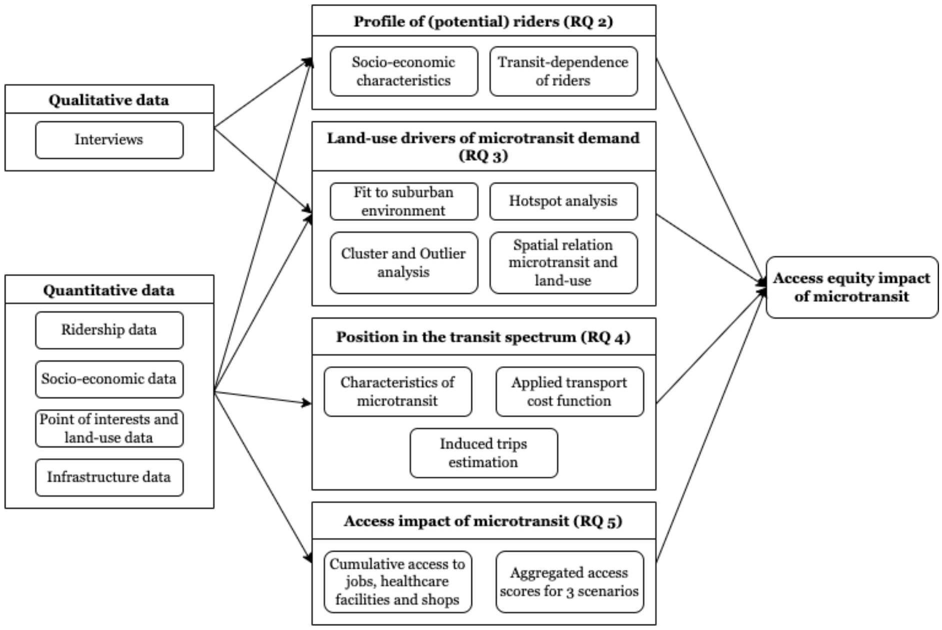


Figure 4.2: Diagram synthesizing the data, analyses and research questions. An extended version can be found in Appendix A

4.6 ANALYSIS TOOLS

In this section, we go into depth on the analysis tools that were used to process the data. Some of the specific code segments for this research can be found on the author's GitHub [Liezenga, 2022].

4.6.1 Statistical Analysis

Throughout the research but especially in Section 5.1 statistical analysis of the survey data was conducted. This analysis was supported by Python, Excel, Pandas, Plotly, Matplotlib, and Numpy. The statistical chi-squared test was also conducted on several occasions. The chi-squared test is a hypothesis test that can be used to determine whether there is a statistically significant difference between the expected frequencies and the observed frequencies in one or more classes. The equation below shows the general method to determine the X^2 value.

$$X^2 = \sum \frac{(O_i - E_i)^2}{E_i} \tag{4.1}$$

In this equation, O_i stands for the observed value and E_i for the expected value. The outcome, X^2 is evaluated based on a distribution table that takes the degree of freedom (the number of classes minus 1) and the degree of certainty, which was always tested at 0.05 and 0.01, and gives a minimum p-value. If the X^2 value exceeds this p-value this shows the significance of the results. This test was applied to the comparison of age, income, and race groups in Section 5.1, and the result of those tests are also shown in Appendix D.

To show the significance of the difference between two distributions, the two-sample Kolmogorov-Smirnov test was employed. This test can show whether two samples come from the same distribution. The test was applied in Section 5.4 to compare the distribution of access with and without microtransit. The SciPy package of Python was used to conduct this test.

4.6.2 Spatial Analysis

When evaluating data on a spatial level, either on individual characteristics, on a spatially grouped level, or based on individual locations (e.g. when evaluating origin and destination of microtransit trips), the tools/packages geopandas, Kepler.gl, OSMNX, and ArcGIS were used. These tools are specifically targeted at geospatial data analysis. Two specific analyses were conducted with the ArcGIS tool: a hotspot analysis and an outlier analysis. The details of these two analyses will be discussed here.

Hotspot analysis finds statistically significant cold- and hotspots based on a set of points using the Gets-Ord Gi⋆ statistic. As input for this analysis, the origins and destinations of the microtransit trips in 2022 (January-April) for both service providers separately were used. This selection was made for two reasons: (i) using more points for this analysis would exceed the computational power available in the used tool, (ii) patterns in travel might change over time, limiting the analysis to one year caused this analysis to be a snapshot of time that could accurately represent the current spatial patterns. The points were clustered into hexagons with a width of 265 or 271 meters and a height of 235. This width was optimized and slightly adjusted to the input data. The analysis was also limited to those points that lay within the municipal boundaries of the service areas. A few points lay outside of this area because they are part of specific location-based services or because the municipal boundaries don't align perfectly with the service area boundaries. This exclusion was limited and acceptable, in part because this research does not focus on these location-specific services. The fixed distance band was optimized for the data set provided and set at 1300 meters for service B and 462 for service A. The analysis was optimized for speed and precision equally.

Cluster and outlier analysis determines whether there are any statistically significant outliers in the spatial distribution of the data. This 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. Again and for the same reasons, the input data was all origins and destinations for microtransit trips for 2022 (January-April). The analyses for the two service providers were conducted separately. The points were clustered into polygons of 230 meters in width and height. The analysis was optimized for speed and precision equally.

4.6.3 Trip Planning

To answer questions 4 and 5 trip planning software was required which would be able to plan a trip from origin to destinations with varying travel modes. For this purpose, OpenTripPlanner (OTP) was employed. OTP is an open-source multi-modal trip planner which can calculate travel times based on traditional transit data and infrastructure data OpenTripPlanner [2022b].

Version 1.3 of OTP was employed because contrary to version 2.0, it allows for one-to-many routing and scripting OpenTripPlanner [2022a], which were required for the analysis. Additionally, there was a larger base of publicly available code found for version 1.3. The trip planning software created graph objects using a combination of OpenStreetMaps extracts, as infrastructure data and selected GTFS files as public transit scheduling data. Due to the computational heaviness of converting several GTFS files into one graph, a selection of GTFS files was made. This selection is shown in Section C.3.2.

After this graph object was created actual trip planning could be conducted. This was done with Jython, a Java implementation of Python. The Jython scripts used for trip planning and some Python scripts used to process the output of the trip planning efforts can be found on GitHub [Liezenga, 2022]. In general, two main scripts were created: one matched one origin to one destination (for existing microtransit trips) and calculated travel time with the different modes for these. The other script took for all origins (centroids of census blocks) and calculate the travel time to all other points of interest, such as jobs, shops, and healthcare facilities, as established with OSM and described above in Section 4.4.2.

4.6.4 Accessibility Analysis

Accessibility was calculated utilizing a cumulative opportunity measure. The cumulative opportunity measure was selected because it is communicatively strong and highly correlated with the gravity-based measure. The access to the three different opportunities: jobs, shops, and healthcare facilities were aggregated into one measure by normalizing the scores and then using the work by Zheng et al. [2019] to combine accessibility levels for different activity types into one access measure.

Access to jobs, shops, and healthcare facilities: the equation below was used (in a Python-coded form) to calculate access to specific points of interest. The trip planning efforts for origins (census blocks) to destinations (points of interest) described above were used to this end.

$$A_{jm} = \sum_{i=1}^{N} O_i * B_{ji}, B_{ji} = \begin{cases} 1 & \text{if } c_{ji} \leq T \\ 0 & \text{if } c_{ji} > T \end{cases} \tag{4.2}$$

The notation is as follows: A_j stands for the accessibility level of a specific location j with a specific mode m, which would be one of: car, microtransit, 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. The threshold T was set at two intervals, one at 30 minutes and 1 hour, reflective of the different degrees to which individuals are willing to travel for specific service types and loosely based on Iacono et al. [2008].

Combining accessibility for different modes: as mentioned before, there were three modes of transit for which travel times were calculated: car, public transit, walking, and microtransit. However, in the final evaluation of access levels, a distinction was made between those with (convenient) access to a car and those without it. For those without convenient access, one possibility without microtransit and one with it was evaluated. Therefore, the fastest transit mode to each point had to be determined.

$$c_{ji} = \min_{m \in M}(c_{ji}) \tag{4.3}$$

Where m is a mode of transport in the set of modes of transport M and $c_j i$ defines the costs as travel time for a specific trip between origin j and destination i. Most often this resulted in public transit being chosen as the fastest mode over walking and microtransit being chosen over public transit within the service area. However, in some cases routes that were not available with public transit were available with walking, and often trips could be taken with public transit which were not in the service area for microtransit.

Aggregated measure: from the three cumulative accessibility metrics one aggregated measure could be calculated. The equation below shows how this aggregated measure was based on the other metrics. This is based on the work by Zheng et al. [2019] which shows the relative importance of access to different fundamental needs. In this equation A_j stands for aggregated access of block group j, $A_{j,shops}$ stands for 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.

$$A_j = \frac{A_{j,shops}}{\sum_{n=1}^{N} A_{n,shops}} \times \frac{0.15}{0.37} \times \frac{A_{j,health}}{\sum_{n=1}^{N} A_{n,health}} \times \frac{0.07}{0.37} \times \frac{A_{j,jobs}}{\sum_{n=1}^{N} A_{n,jobs}} \times \frac{0.15}{0.37} \tag{4.4}$$

4.6.5 Lorenz Curves

To communicate the results of the accessibility analysis Lorenz curves and Gini coefficients were used, 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 that resource. A typical Lorenz curve applied to access inequality is displayed in Figure 4.3. The area between this curve and the 45-degree angle in the plot determines the Gini coefficient, which is a quantified measure of inequality The Gini coefficient is calculated in the following way:

$$G = \frac{A}{A+B} \tag{4.5}$$

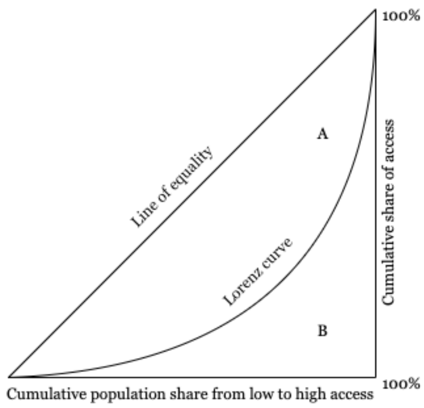


Figure 4.3: Example of the basic lay-out of a Lorenz curve for the purpose of measuring the distribution of access.

5 RESULTS

In this section, the results of this study will be presented and analyzed. The components of the conceptual model of accessibility (Figure 2.1) will be used to give structure to this chapter, discussing the individual (Section 5.1), land-use (Section 5.2) and transport component (Section 5.3) and finalizing the findings with a section on accessibility to opportunities (Section 5.4).

5.1 THE INDIVIDUAL COMPONENT

This section will aim to answer the following research question: 'How do the individual characteristics of (potential) riders co-determine the choice for and usage of microtransit as a mode of transport?' The individual component reflects the needs, abilities, and opportunities of individuals. These characteristics influence the individual's level of access to transport modes, including microtransit, and to opportunities [Geurs and Van Wee, 2004]. We will focus on the first. The following potential relations between individual characteristics and access to and actual usage of microtransit will be discussed:

- Several socio-economic characteristics influence a person's ability to interact with the (micro)transit system. The set of socio-economic characteristics that was studied here was selected based on a combination of relevance and availability. These characteristics are known to relate to transit usage, vulnerability as a transit rider, and sensitivity to transit interventions, as will be shown per characteristic below. These five characteristics had data available from the census, microtransit survey, and in some cases also the (traditional) public transit survey.
    - Income can dictate how much individuals are willing and able to spend on transit. Additionally, low-income individuals are more likely to be transit-dependent and are known to benefit most from transit interventions in terms of daily activity rates and access to jobs [Yan et al., 2022; Allen and Farber, 2020; Denmark, 1998]
    - Age impacts demand for transit as well as which modes are options. Distinct patterns were identified in to which extent different age groups use novel ride-hailing services [Haglund et al., 2019; Lazarus et al., 2021]. The elderly are also often mentioned as a vulnerable group for transit by Denmark [1998]. This group regularly faces physical difficulties, that may cause fear of crowding, falling, and difficulty entering and exiting vehicles [Denmark, 1998].
    - Disability status can determine whether a person can use a transit mode. Disabled riders are also mentioned as a vulnerable group for transit by Denmark [1998], because of an often limited ability to get on and off vehicles and reach stops.
    - Race contributes to the vulnerability of riders. In particular, marginalized and/or minority groups are often listed as having a general difficulty in accessing transit [Denmark, 1998]. In this research study, a distinction is made between white and non-white individuals, where non-white individuals are considered a marginalized, minority group.

  - Gender contributes to the usage and vulnerability of riders. An overview by Hail and McQuaid [2021] demonstrated that women have more complex mobility patterns than men that are often not in line with the patterns the transit system was designed for. Women also face more issues regarding the safety and physical design of vehicles [Hail and McQuaid, 2021].

- Access to cars/car ownership also co-dictates choice of transit mode. As exemplified by Yan et al. [2022] car owners and transit-riders can have very diverging levels of job accessibility.

As mentioned in Chapter 4 the following data sources will be employed: (i) two interviews conducted with the service providers in the case study area, (ii) survey data on the socio-economic characteristics of riders, and (iii) ridership data of all trips conducted in the service areas.

5.1.1 Socio-economic Characteristics

Income: a comparison of the reported income in the survey data and the overall population income in the service areas shows a clear and highly significant difference in income level for microtransit riders (see Appendix D). Microtransit is able to reach the population in lower-income brackets. 55.54% of survey respondents have a household income below $25.000 whereas in total in this region only 8.16% falls into this income bracket. Additionally, microtransit reaches more riders in this income bracket than (traditional) public transit does, for which only 14.37% of riders fell into this income bracket (Section D.1). This could be the result of the low costs of microtransit services (compared to ride-hailing and personal car ownership). However, this hypothesis is not confirmed by the latest survey round: low-income riders did not indicate price as a reason for choosing microtransit over another mode significantly more often than the respondents overall did (Section D.1). However, the fact that microtransit does significantly reach more low-income riders is a positive contribution to access equity, since low-income riders are most sensitive to significant improvements in daily participation rates through transit improvements.

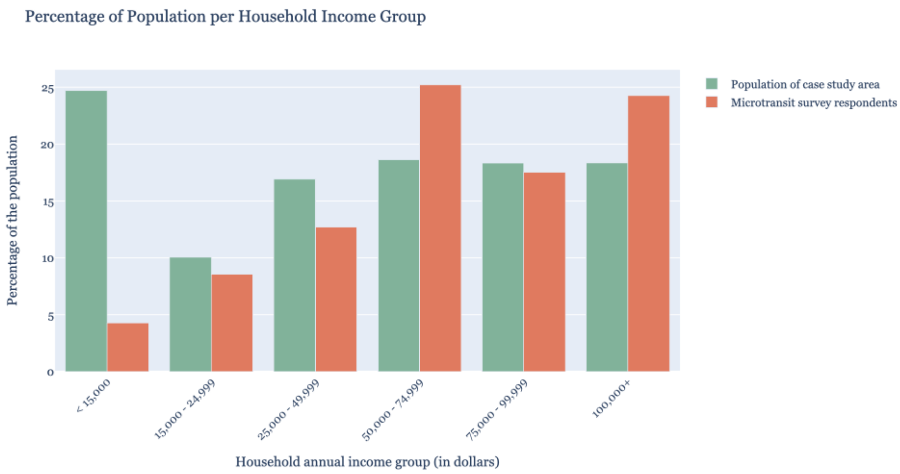


Figure 5.1: Distribution of annual household income for microtransit survey respondents and the general population of the area (census data).

In addition to this self-reported income, which is only available for the survey sample, a more generalized method to find the income level of microtransit riders was attempted. This was done by aggregating the presumed residence (origin before 11, destination after 16) of microtransit riders into block groups and comparing the rides per head of population to the median household income of that block group. This did not result in a clear relation between microtransit ridership and income (results can be found in Section D.1.1). This might show that the income groups in the studied area are not spatially clustered. In this way, microtransit can reach the few low-income individuals throughout the area without necessarily becoming spatially clustered or concentrated.

Age: microtransit riders also hold a significantly different age distribution than the overall age distribution. Initially, this difference seemed to be caused by the low amount of riders under 18 (only 4.28%) while the general population consists of 24.72% under 18. However, even when excluding this group the difference remained significant, with microtransit majorly reaching riders in the age brackets 35 to 44 and 55 to 64. The findings contradict the idea that microtransit reaches majorly young riders: the number of riders in the 18 to 34 bracket is actually lower than in the overall population. Compared to traditional public transit microtransit reaches significantly more 55+ users (Section D.2) and less 18-34 users.

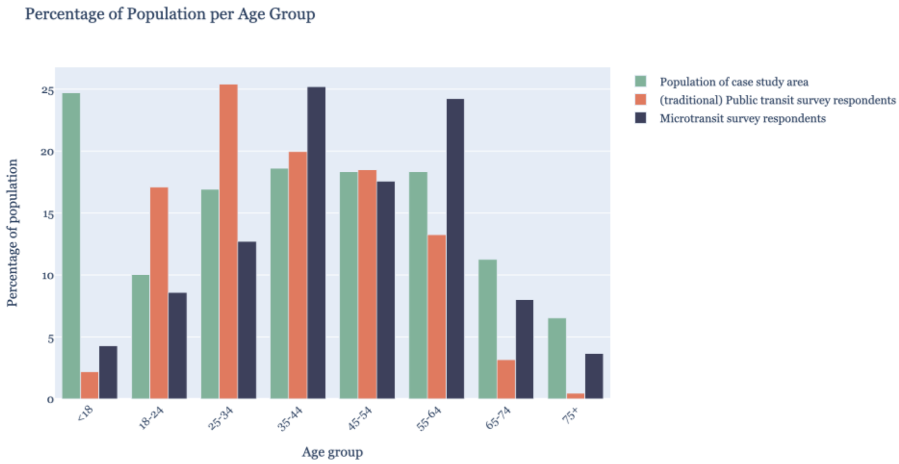


Figure 5.2: Age distribution for microtransit and public transit survey respondents and the general population of the area (census data).

This finding suggests that microtransit can reach older user groups, which was a challenge of both the traditional public transit and new ride-hailing services. This might be caused by the ease with which microtransit is used: the curb-to-curb service does not require walking to a stop and allows for more time for getting into the vehicle. Additionally, both studied services are integrated with the existing public transit provider, removing the barrier of contacting a 'new' authority to book trips. Based on the most recent survey no significant differences in reasons for choosing microtransit can be identified between the different age subgroups of under 34, 35-64 and 65+. Overall, reaching the older age group is a positive contribution to access equity because this is a vulnerable group of riders that is difficult to reach.

Disability: microtransit also manages to be inclusive of disabled riders. Self-indicated disability status of microtransit riders was at 33.1% in the region while, according to the Census Bureau, only 7.8% of inhabitants had a disability. The traditional transit in the area only reached 5.7% disabled riders. This difference could be the result of a variation in what people consider a disability across surveys and time as well as the attractiveness of microtransit to disabled riders. Microtransit is potentially attractive to disabled riders because it is a curb-to-curb service and does therefore not require walking to a stop but also because of the advertised compliance to the Americans with a Disability Act (ADA) of one of the services. In the survey, disabled riders more regularly indicated choosing microtransit because it was safer and better suited to their needs (Section D.4).

Race: significantly more non-white riders find their way to microtransit than live in the area in general. This is also the case for traditional transit, though to a lessened extent (Section D.5). Reaching this traditionally vulnerable group to a greater extent than traditional transit positively contributes to the access equity impact of microtransit. The factor of race is especially relevant because of the current shift of marginalized racial groups from the urban core to the suburbs.

Gender: no significant differences were identified in whether users were male or female compared to census data. In the survey, it was found that women do indicate safety and price more often as a reason for choosing microtransit than men, with men mentioning convenience and reliability more often (Section D.3). Since safety is also a reason why women traditionally are less attracted to public transit [Hail and McQuaid, 2021], it is positive that microtransit (to some degree) can mitigate this barier.

5.1.2 Transit-dependence

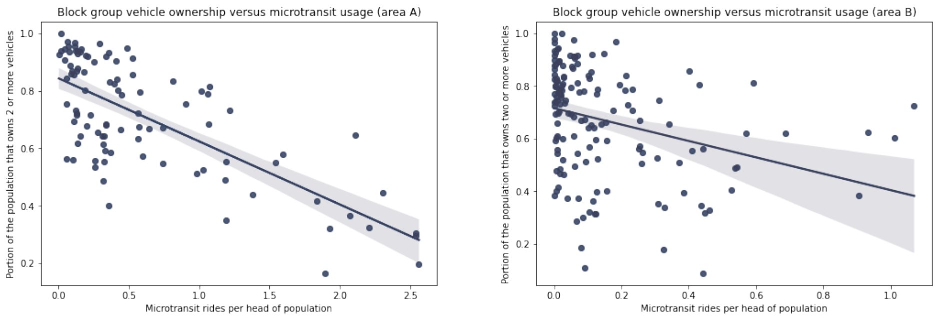
In the practice of transit planning, a distinction is often made between transit-dependent and choice riders. During the interviews with both service providers it was emphasized that, based on experience in public transit, a more transit-dependent (and lower-income) audience was initially expected for the microtransit service. However, both providers expressed that along the way more choice riders joined the network. Neither thought this was a negative development and both recognized that it was a logical effect of the demographics of the area in which the services operate.

The area has a high number of choice riders, which can be derived from the high vehicle ownership and car dependence. 97% of the population owned at least one vehicle and 70% owned two or more vehicles. In 2020, 85% of the population of the area indicated that they traveled to work by car, van, or truck. Only 3.3% of inhabitants indicated using public transit as their commute mode. This shows that car ownership is high and transit dependence is overall low. This also explains why the traditional public transit services were lacking: they were not needed traditionally. On the other hand, this makes it even more important that the transit-dependent minority still has a decent level of access.

Even though the service area constitutes mainly out of choice-riders, it might still be the case that microtransit riders are more (micro)transit-dependent. One indicative factor of this is the number of people that say they would have taken their trip with another mode of transport if microtransit were not available. In total 28.6% of respondents indicate that they would not have taken their trip if microtransit were not available. Interestingly enough this percentage does not differ that much for the two service areas even though transit availability in service area B is much higher. This relatively high percentage indicates that there is a small but significant user group that is or has grown, (micro)transit-dependent.

Figure 5.3 plots vehicle ownership versus presumed residence of microtransit riders per block group. A relation between these two variables can be identified in area A (R-squared: 0.525) but not in the younger service area B (R-squared 0.142). It is important to note that vehicle ownership and income are highly correlated (Section D.1.1). This indicates that microtransit usage is more prevalent amongst the low car ownership group.

'Super' users: a final indicator of transit dependence is repeat use. One of the service providers even indicated that they experience 'super' users who use microtransit for all their daily activities. Repeat use of microtransit might indicate dependence, whereas single-use might indicate incidental use by a choice rider. However,



(a) Area A

(b) Area B

Figure 5.3: For both service areas, trips per head of population plotted against portion of the population that owns 2 or more vehicles, with an OLS regression line fitted to the data.

even repeat users can be choice riders who have made a transition from car use to (partial) microtransit use. 74% of riders use microtransit at least once a month, with an average of 10.7 trips a month. 71% of riders use microtransit at least once a week, with an average of 4.5 trips a week. This level of usage does seem to indicate (partial) dependence on and integration of microtransit into the daily routine of users.

5.1.3 Summary

Overall these findings suggest that in the studied area microtransit reaches vulnerable groups: both low-income, non-white, elderly, and disabled individuals seem attracted to the transport mode. Women and men are equally represented in the sample of survey respondents. Through reaching these vulnerable groups microtransit fulfills the role of serving communities that traditionally struggle to use public transit. Additionally, the notion that microtransit, like other innovative modes of transit, would only be used by a younger demographic is presented with counterarguments in this case. No concrete conclusions can be drawn about the relation between car ownership and microtransit usage, though the findings from the interview, repeat rates, and overall car ownership in the area do seem to suggest that microtransit is used by a smaller group of transit-dependent riders alongside a larger group of choice-riders. This can be majorly explained by the overall demographics of the area.

5.2 THE LAND-USE COMPONENT

This section will aim to answer the following research question: 'How does land-use impact the spatial distribution of microtransit trips?' The land-use component reflects the land-use system, which consists of (i) the amount, quality, and spatial distribution of opportunities at destinations and (ii) the demand for these opportunities at origins [Geurs and Van Wee, 2004]. But for this research, the liberty of utilizing a slightly wider definition and thereby also considering the suburban land-use characteristics of our case study area is taken. The following potential relations between land-use characteristics and access to and actual usage of microtransit will be discussed:

- The suburban land-use environment and how it might or might not form a suitable environment for microtransit networks.
- The land-use characteristics of the area and how they might be related to the origin and destination pairs as well as hot spots.

- The statistically significant spatial hot and cold spots, clusters, and outliers formed by origins and destinations of microtransit rides.

5.2.1 The Suburban Environment

The case-study area is an example of a suburban land-use environment. This kind of area has specifically gained interest because of its transit challenges due to suburbanization of poverty, decades of car-centric policies, and urban sprawl [Stacy et al., 2020]. Microtransit has the potential to solve these problems in the suburbs for three main reasons: (i) the lack of (interest in) traditional transit services and (ii) the relatively large distances between points of interest (housing and jobs, services, amenities, etc.) due to urban sprawl (iii) the decrease in car ownership and income due to the current suburbanization of poverty. Creating a new, more convenient, and more flexible form of transit microtransit can fill the gap of lacking public transit without the risk of ineffective routes.

One of the service providers mentioned during the interview: 'Microtransit has the ability to make suburb to suburb transit a reality in a way that it never has been before.' Especially in service area A, the operation of fixed-route transit had been attempted several times over the years but was never effective in terms of cost and user experience. When services like Uber and Lyft came to rise in the 2010s the idea of creating a similar service was planted in the minds of the transit operators. This has been successful: both operators expressed that the service soon gained traction among inhabitants and continues to grow, as is also reflected by the data. Within the scope of this research, it was not possible to compare the success in suburbs to experiences in rural or urban (core) environments.

5.2.2 Land-use characteristics

Figure 5.4 and Figure 5.5 show the aggregated land-use characteristics of the case study areas. In these images, light green means residential land-use which is a combination of attached, detached, and mixed usage housing, the blue/aqua areas represent (mixed-use) retail and commercial areas. Purple represents transport land-use, which might be a station, a railway, or major road but also an airport as can be seen in Figure 5.4 in the South-Eastern segment of the service area. Dark orange represents industrial or utility areas, for example the location of a power plant or heavy industry. The lighter orange represents institutional land-use which includes town halls, schools, churches, and hospitals. The lightest orange represents parks and recreational areas as well as golf courses which are plentiful in both areas. Light green represents offices, and light yellow represents other land-uses, including undeveloped, open water, and extractive areas. Lastly, the agricultural land-use is depicted in burgundy. Most of the agricultural areas are at the edge or just outside of the service area. The service area is highlighted in the image. Overall the land-use in both areas is predominantly residential with many parks and some spots of retail and commercial as well as transport land-use in between. This seems typical for the suburban environment.

For all origins and destinations of the rides aggregated land-use was analyzed. This results in two points evaluated per ride. As shown in Figure 5.6, 41% of these points are in the residential environment, similarly around 80% of trips involve the residential environment. The second-largest land-use is retail and commercial, making up 31% of points. This suggests that microtransit is used majorly to connect residents to (commercial) points of interest.

In terms of combinations of land-use Figure 5.7 shows that 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. After this, residential land-use is coupled to transport, institutional, industrial or utility, and other residential for

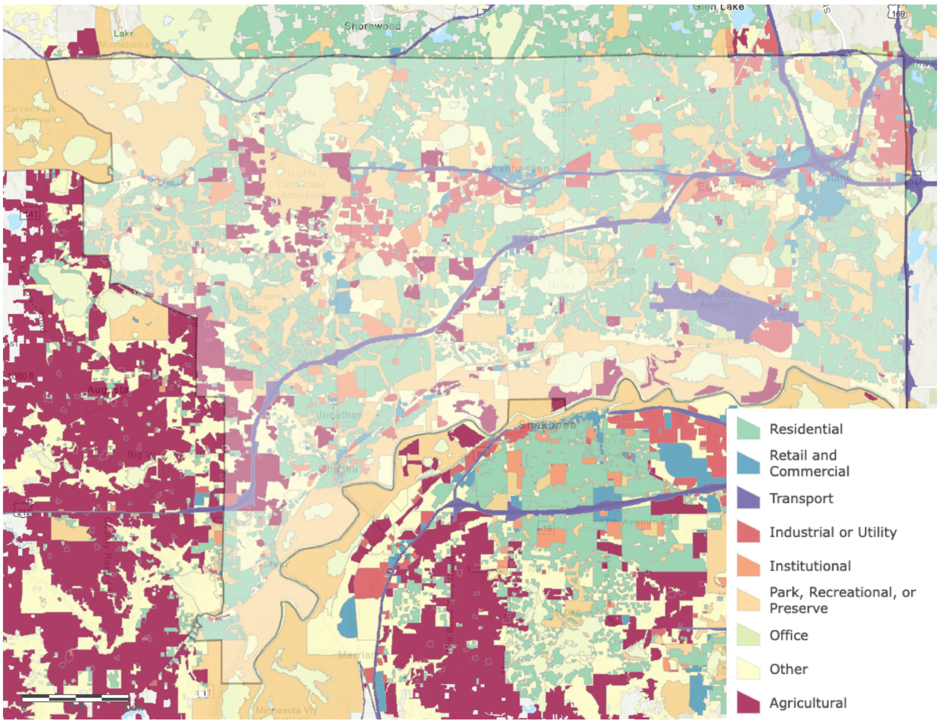


Figure 5.4: The land-use characteristics of service area A depicted by color. The service area is demarcated with a thin line.

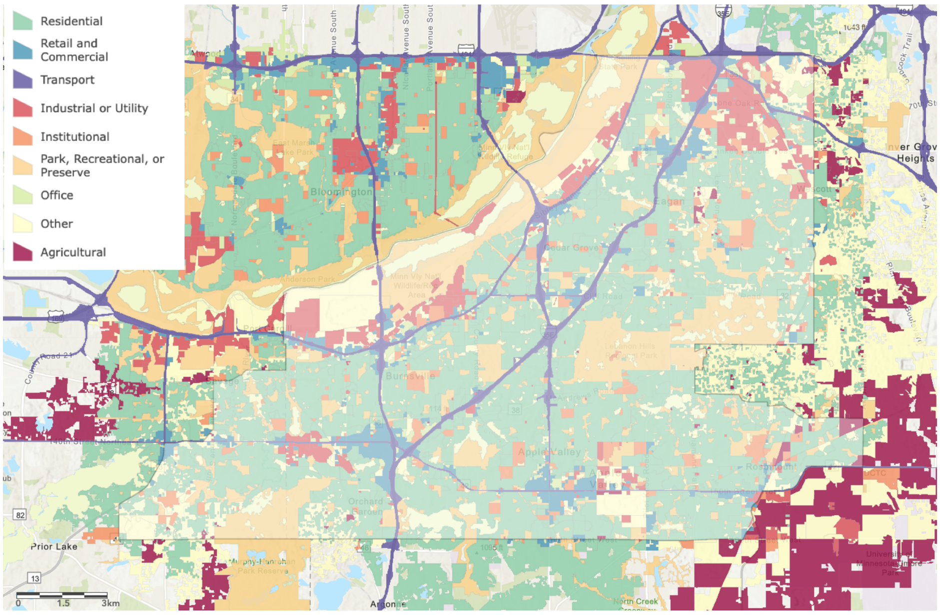


Figure 5.5: The land-use characteristics of service area B depicted by color. The service area is demarcated with a thin line.

6-9% of trips. Lastly, 6% of trips combine retail and commercial areas with other retail and commercial areas. These findings can be matched to the indicated travel purposes of survey respondents, as seen in Figure 5.8, and underlying data can be found in Section D.8. In the survey, the most common travel purpose is work/commute and the second most common purpose is shopping. Both can be coupled to the retail and commercial land-use, though work can be coupled to institutional, industrial, or utility land-use as well. These findings suggest that microtransit holds the position of majorly matching residences to points of interest, most prominently commercial centers.

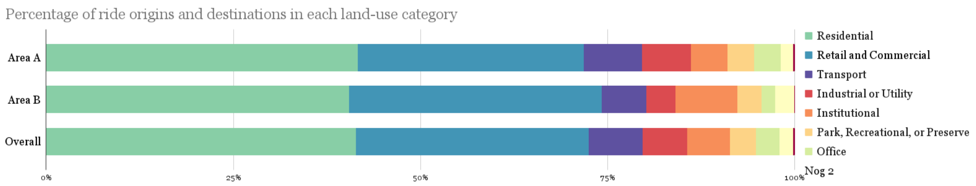


Figure 5.6: The distribution of trip origins and destinations across different land-use types for the service areas separately and combined.

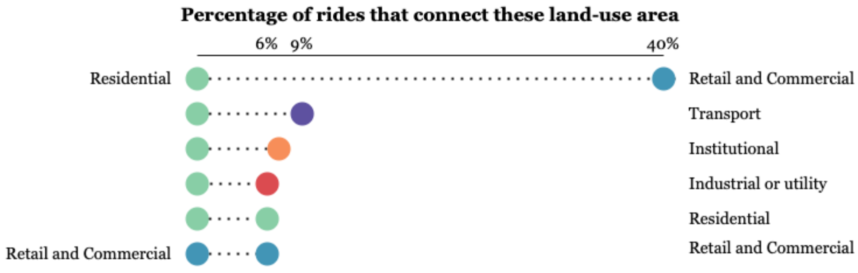


Figure 5.7: The most common combinations of land-use for trips by percentage of rides with that land-use combination.

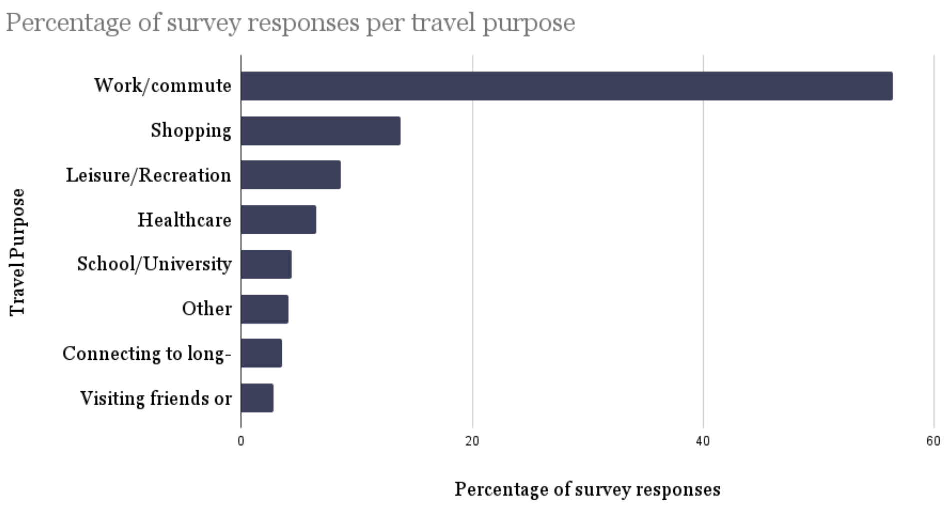


Figure 5.8: Travel purposes indicated by survey respondents, ranked by most common responses.

5.2.3 Spatial Analysis

Two types of spatial analyses were conducted based on trip points for January-April 2022. This resulted in a hot and cold spot and cluster and outlier analysis that are discussed and combined with the land-use characteristics here. However, first, a visual inspection of the most popular routes is conducted.

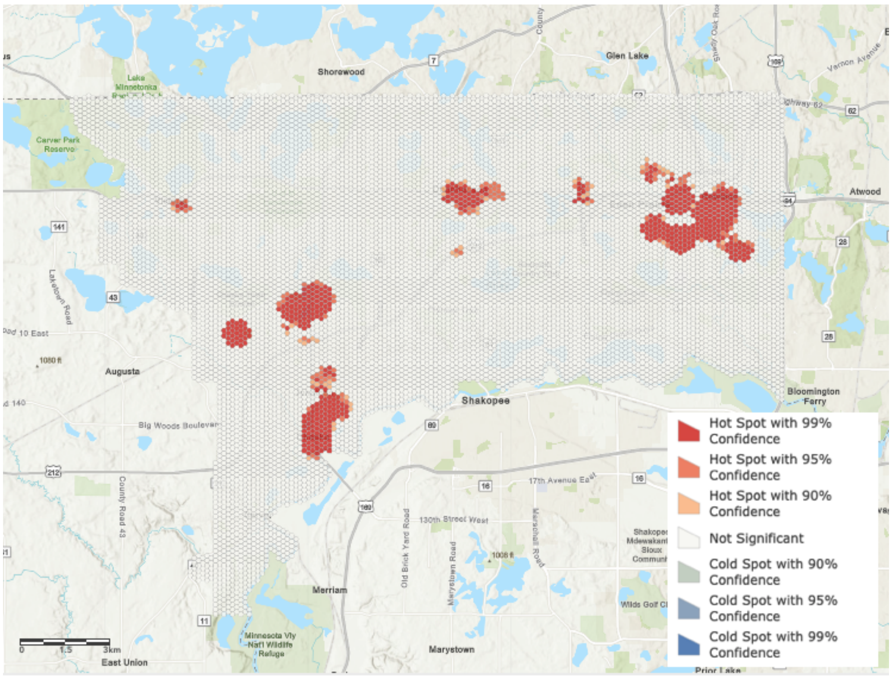
Popular routes: the most popular points in both service areas were clustered and the connections between them were ranked in terms of popularity. This resulted in the visualization in Figure 5.9 which already visually displays the aforementioned pattern of matching commercial centers to the outskirts of the service areas. This creates a visual sense of the data, after this more quantitative evidence for this relation will be presented.

(a) Area A.

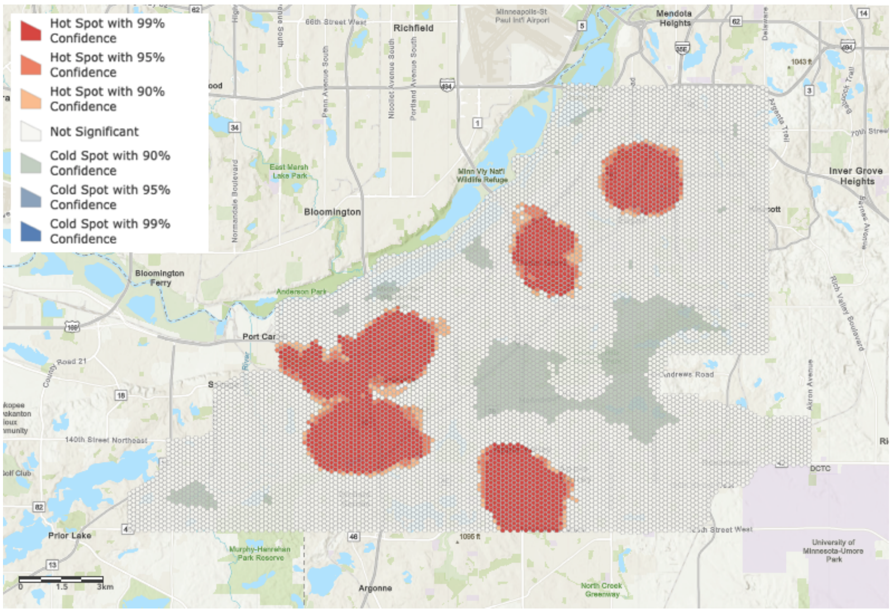
(b) Area B.

Figure 5.9: The most common combinations of clustered trip origins and destinations, planned with OSMnx and displayed with opacity as an indicator of the popularity of that trip (higher opacity means more popular), for both service areas.

Hotspot analysis: in a hotspot analysis statistically significant cold and hotspots of points are identified. Figure 5.10a and Figure 5.10b show the significantly significant hotspots for both areas. No cold spots were identified in area A but a few tentative cold spots were identified in B. The hotspots in A were more concentrated than in B. Overall, the fact that hot spots are clearly and significantly identified whereas cold spots are sparse to non-existent indicates that riders come from throughout almost the entire service areas (presumably their residences) to specific areas that form hotspots.



(a) Area A

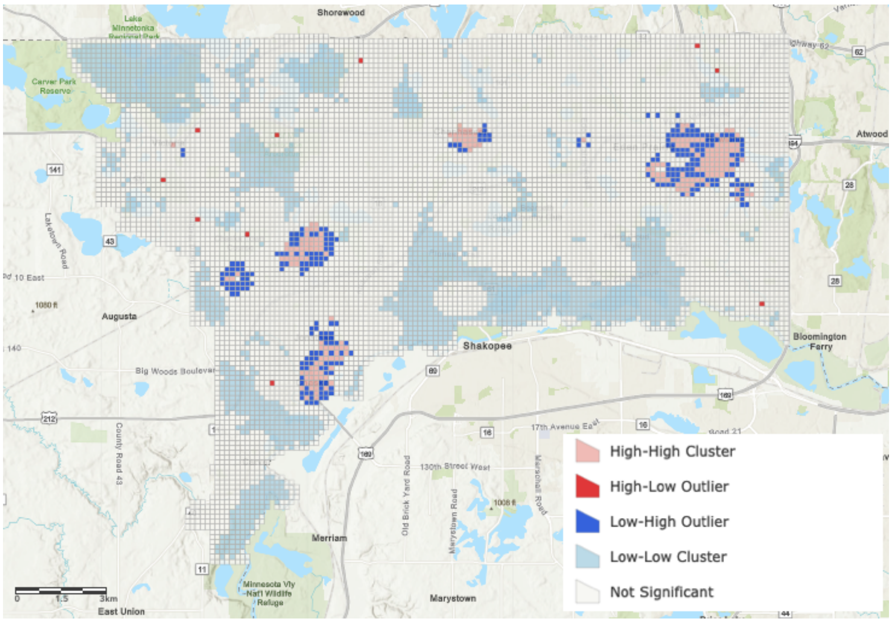


(b) Area B

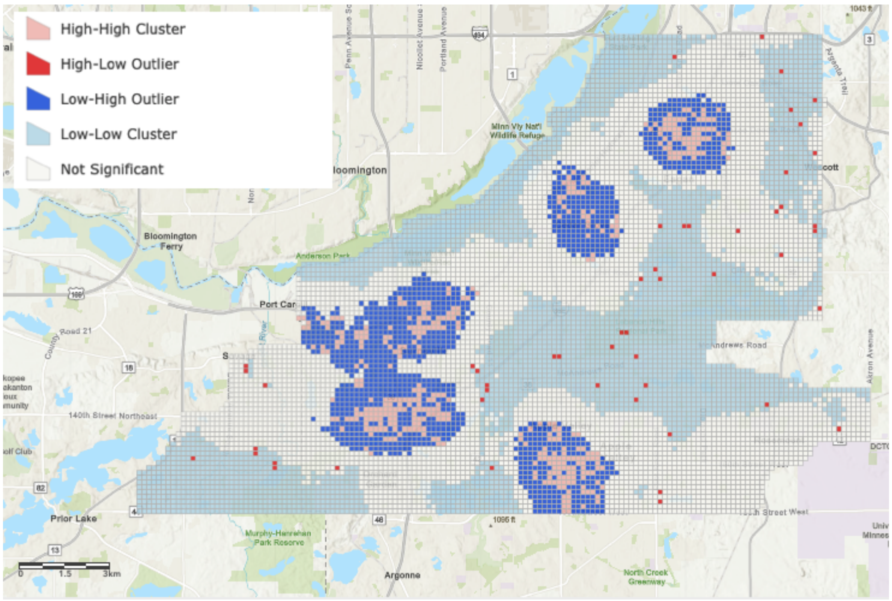
Figure 5.10: Hotspot analyses on the trip origins and destinations for 2022, precise parameters can be found in Chapter 4, processed with ArcGIS.

Cluster and outlier analysis: this analysis could be seen as an extension of the hotspot analysis, in which the statistically significant hotspots, coldspots, and spatial outliers are identified using the Anselin Local Moran's I statistic. This results in clusters of high points surrounded by other high points, high points surrounded by low points, low points surrounded by high points, and low points surrounded by low points. These analyses for both areas are presented in Figure 5.11a and Figure 5.11b.

This analysis gives a more precise indication of which areas within the hotspots are the actual values that most travelers travel towards or from. A question that comes to mind instantly is what causes these hotspots, or high-high clusters in particular. This is demonstrated by Figure 5.12a and Figure 5.12b which overlap the cluster and outlier analysis with the retail and commercial land-use. It is clear from a visual inspection that most high-high clusters can be linked to retail and commercial centers. There are some spotty high-low clusters throughout both areas, which do not necessarily overlap with one specific land-use type. These spotty clusters might be caused by super-users, individual users who use microtransit to such an extent that it shows on these maps. These super users presumably live in residential areas and are therefore surrounded by lower levels of microtransit usage.

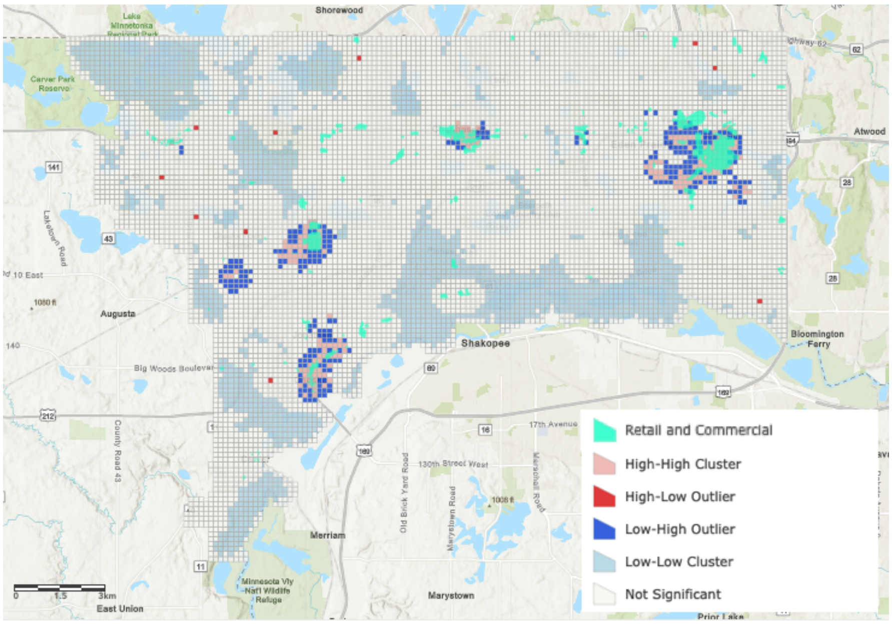


(a) Area A

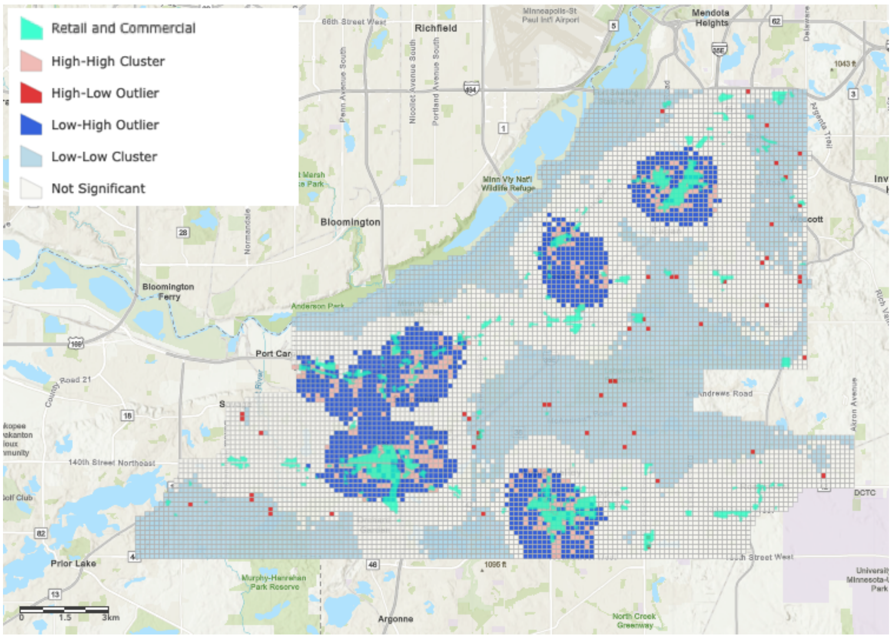


(b) Area B

Figure 5.11: Cluster and Outlier analyses on the trip origins and destinations for 2022, precise parameters can be found in Chapter 4, processed with ArcGIS.



(a) Outliers and retail and commercial land-use, area A



(b) Outliers and retail and commercial land-use, area B

Figure 5.12: Outlier analyses, overlapped with retail and commercial land-use, conducted in ArcGIS.

5.2.4 Summary

Based on the interviews, the suburban land-use environment and its current challenges seem to fit the characteristics of microtransit well. In this environment, microtransit might fill the gap left behind by the lacking (traditional) public transit network. The suitability of microtransit to the suburban land-use environment can be caused by (i) the lack of traditional public transit services in this area, (ii) the relatively large distance between residences and services and amenities due to urban sprawl (iii) the onset decrease in car ownership and income levels due to the ongoing suburbanization of poverty.

The land-use analyses show that there are significant hotspots to be identified for the microtransit rides in the studied areas and that these overlap with the retail and commercial centers in terms of land-use. It can be observed that most trips involve residential land-use and 40% match commercial land-use to residential land-use. The fact that most trips involve residential land-use shows that most riders travel from their residence to a point of interest. In many cases, this point of interest is related to their work, as is supported by Figure 5.8. It has also been demonstrated that there is a clear relation between land-use and microtransit trips and it is one in which microtransit couples residential areas with points of interest, mainly commercial areas.

5.3 THE TRANSPORT COMPONENT

This section aims to answer the following research question: 'How does microtransit as a mode of transport compare to, complement, and compete with other modes?' The transportation component describes the transport system expressed as the ability of an individual to travel from an origin to a destination using a specific transport mode. Included in the 'costs' of such travel are time, costs, and 'other' [Geurs and Van Wee, 2004]. The following potential relations within the transport component impacting access to opportunities will be discussed:

- Microtransit is a new mode of transport with distinct characteristics. It can be compared to the other modes of transit to gain insight into how users decide between them.
- By providing a new alternative to other modes of transport microtransit can alleviate the costs, travel time, and/or other factors that impact (choice of) transit. By alleviating these combined 'costs' of travel microtransit can increase accessibility levels.
- Additionally, microtransit might induce new trips that would not otherwise have been taken, directly impacting the access level of residents.

5.3.1 Characteristics of Microtransit

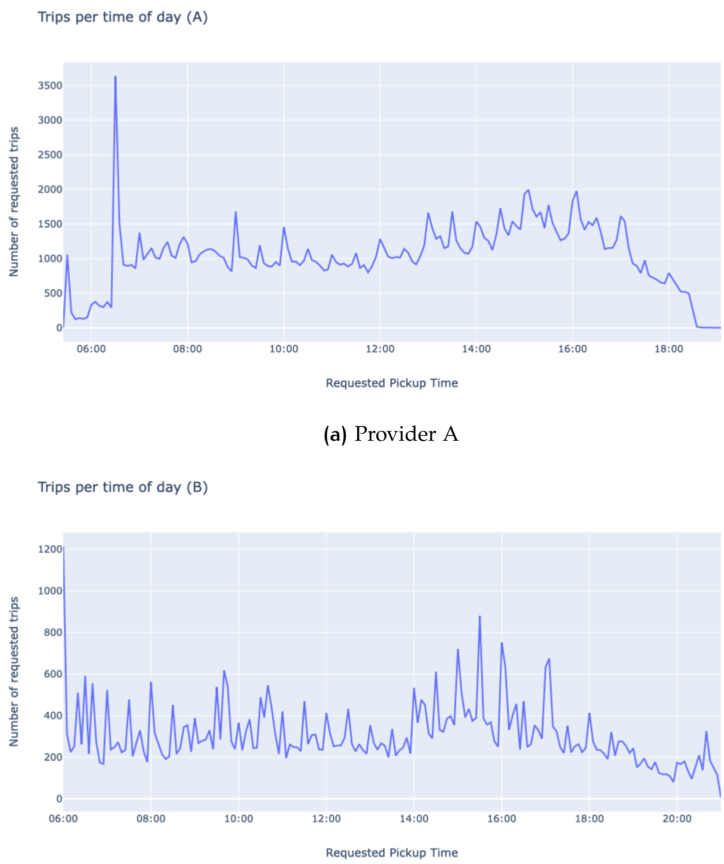
In this subsection the characteristics of microtransit and microtransit trips are briefly discussed.

Length: for the studied area the average microtransit trip length was 12.3 kilometers. A definite difference could be observed here between the two service providers, where service provider A had an average trip distance of 14.2 kilometers and B of 6.9 kilometers.

Duration: the average trip duration was 14.4 minutes, with an average wait time of 16.6 minutes. This suggests the predominant usage of microtransit for shorter trips: only 36.5% of trips are longer than 15 minutes, only 7% longer than 30 minutes.

Temporal: in the case study area the hours during which the microtransit network rides are limited. One of the services does not run on Sunday and both restrict their times from early morning to early evening. Figure 5.13 shows the distribution of trips across the day. Both services have extreme peaks in the early morning shortly after or at the opening time. Besides those morning peaks, the demand is relatively evenly distributed across the day.

Spatial: an important factor to address is that there the service area of microtransit is limited to specific places. However, both networks have made attempts to expand their service in directed ways toward hotspot areas like an airport or a university campus. This can improve the access level of users greatly since it might result



(a) Provider A

(b) Provider B

Figure 5.13: Temporal distribution of trips throughout the day, rounded to 5 minutes.

in additional opportunities within their range of travel time and costs. The spatial distribution of microtransit trips is further addressed in Section 5.2.

This list of characteristics shows an image of a service that is used over semi-long distances but within a demarcated spatial area that does not reach beyond the municipal boundaries of the joined cities it serves. It also shows a service whose operation is focused on the weekdays and daytime but is spread out across the day within that scope.

5.3.2 The Transport Cost Function Applied

In this subsection the three factors in the transport cost function $Mode = f(c, t, o)$ are studied, where c is costs, t is time and o is other, to establish how microtransit compares to other modes. The findings will be summarised with a table (Table 5.2).

Time

For the three most important potential replacement modes, the microtransit rides were scheduled with the trip planner to retrieve alternative travel times. An example of how these different travel times would reflect on a real-world case is shown in Figure 5.17. An important distinction is made between microtransit in-vehicle travel time and wait time.

Car: Figure 5.14 shows the comparison of car travel time and microtransit travel time. Logically, the personal car is still faster than microtransit since it does not require picking up and dropping off other riders. However, the degree to which it is faster is limited, especially when excluding wait and walking time. This shows that the microtransit service is quite efficient in its routing of rides.

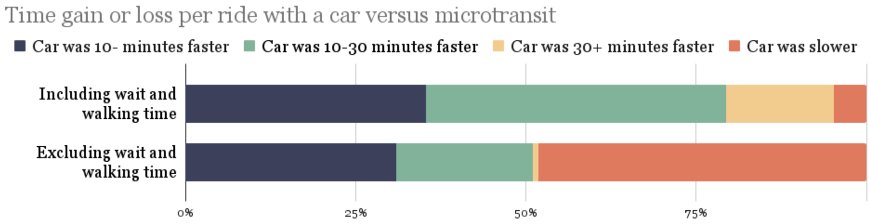


Figure 5.14: Time gain or loss for riding a (personal) car versus riding microtransit, for all microtransit trips studied.

Public Transit: for all the rides public transit options were evaluated. What was especially compelling in this analysis is the extreme walking time that people in this area have to take into consideration when taking public transit (on average around 5 kilometers). The data demonstrates that the public transit network is not able to answer the demand that microtransit is now serving. In 70% of the cases, there were no public transit alternatives found. Figure 5.18 depicts the size and extent of the public transit network in the service areas. It can be observed that the network in A is extremely limited. For service area B the public transit network is more enhanced and could take some of the demand from microtransit. Still, only 55.38% of the trips taken in area B have a public transit alternative, and it is rarely faster than microtransit.

For the trips that did have a public transit alternative, the travel time gains and losses are shown in Figure 5.15. It is clear from this figure that if there is a public transit alternative, it requires much more time than the microtransit alternative. This clearly shows that microtransit has become a vital part of the transit network in these areas.

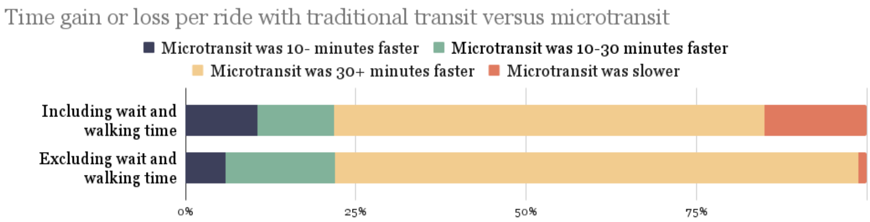


Figure 5.15: Time gain or loss for riding microtransit versus riding public transit, for all microtransit trips that had a public transit alternative.

Walking: the walking alternatives for the microtransit rides were also evaluated to investigate whether riders might be taken over distances that would have been feasible to walk. This does not seem to be the case since the average time gain with microtransit approximates an hour. It should not only be considered that this is quite an extensive amount of time to walk for any person, but also that a major part of microtransit riders (33.1%) indicate having a disability. Disabilities come in many shapes but in some cases, it might rule out such an extensive walking option altogether.

Initially, cycling was also taken into consideration as a travel option. However, since its usage amongst microtransit riders seems limited based on the survey and

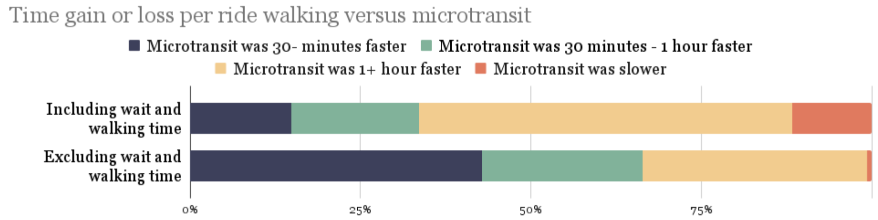


Figure 5.16: Time gain or loss for riding microtransit versus walking, for all microtransit trips studied.

the trip planning efforts showed that the infrastructure for cycling in the area is lacking, it was excluded from this comparison.

Figure 5.17 illustrates a hypothetical example of the travel time for the 4 different modes studied here. From this example and the data provided above we can readily notice that the public transit and walking alternatives are often unfeasible. What we can also see is that the time gained by riding a (personal) car, though significant, might not be as important to the rider on the time scale of the average microtransit trip.

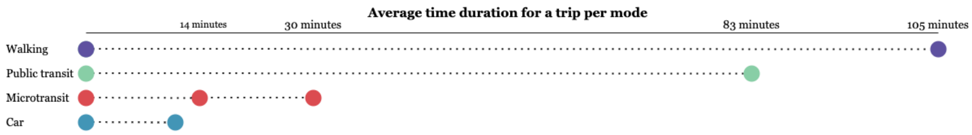


Figure 5.17: Illustrative comparison of travel times for different modes based on the average trip duration of microtransit rides. Microtransit is split up into in-vehicle and wait time.

Ride-hailing: microtransit is regularly listed by users as a replacement for ride-hailing. No systematic estimations could be made of travel time with ride-hailing but we assume here that, due to the nature of ride-hailing, the travel time is similar to that of cars and that there is a small added wait time.

Cost

Table 5.1 shows a comparison of costs per studied mode. Walking is excluded from this comparison since it bears no costs. Microtransit is cheaper than cabs and ride-hailing, though slightly more expensive than traditional public transit. Riding a personal car can be cheaper when taking very long trips and/or when making use of the vehicle regularly. However, the use of a personal car requires initial investment as well as regular maintenance costs. This makes it a less attractive option in particular to low-income individuals. For those that already own a vehicle, microtransit is relatively expensive compared to the costs of driving their personal vehicle.

Mode	Annual	Set (per ride)	Variable (per km)
Microtransit	-	$3 - $4	-
Public transit	-	$2 - $3.25	-
Ride-hailing (Uber)	-	$2.61 (base), $7.49 (minimum)	$0.52
Taxi	-	$5	$1.56
Private car	$7542	-	$0.10

Table 5.1: Costs of travel per year, ride and mile for the different potential modes [Uber Technologies Inc., 2022; SIR Media GmbH, 2017; SouthWest Transit, 2022; MVTA, 2022; IEA, 2020; AAA Gas Prices, 2022; AAA, 2019]

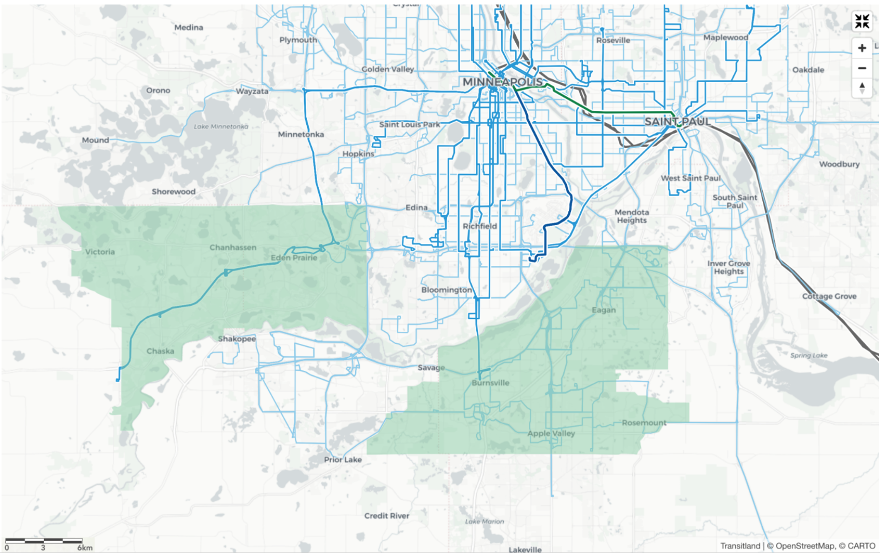


Figure 5.18: The public transit network in the case study environment, retrieved from Interland Technologies [2022]

Other

Besides costs and travel time, other reasons might weigh in on a rider's mode selection. This third factor is called 'other'. To gain insights into this 'other' factor, riders were asked why they choose microtransit over other services. The most common reason for choosing microtransit was that it was cheaper (58.9%) and that it was considered more convenient (51.4%). When looking at specific replacement modes of those that choose microtransit (see: Figure 5.19) we see that the largest alternative listed is ride-hailing. For the riders that listed ride-hailing as their alternative mode costs were mentioned as the most prominent reasons for choosing microtransit (85.6%). For riders who alternatively would have chosen a private car, convenience was the most prominent argument (74.6%) to opt for microtransit instead. Overall this demonstrates that riders themselves also observe the cost-benefit of microtransit over ride-hailing and that choice riders find microtransit a convenient option of travel over personal car use.

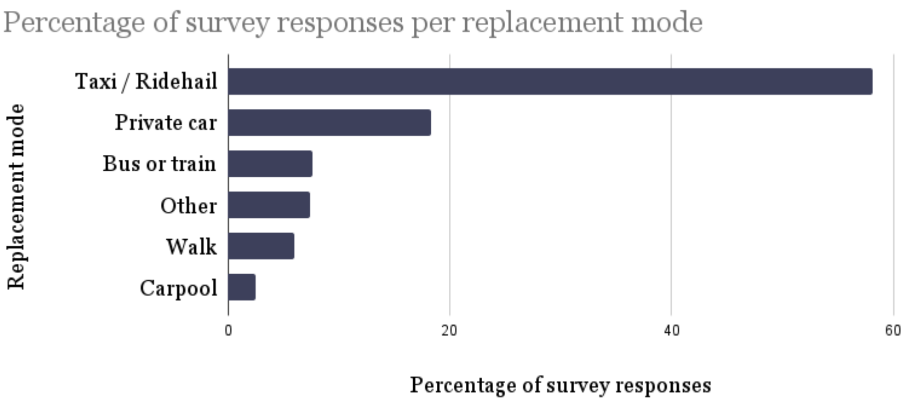


Figure 5.19: Replacement mode indicated by survey respondents, ranked by most common responses.

Comparison

Table 5.2 shows a summary of how microtransit compares to other modes of transit. This is a qualitative evaluation based on the quantitative information listed above, including the survey responses. This comparison shows that across different dimensions microtransit can have different competitors.

For example, for transit-dependent riders, microtransit is a great alternative to public transit and walking in terms of travel time and availability and a significant improvement compared to ride-hailing in terms of costs. Additionally, microtransit might induce many trips in this group because public transit and walking alternatives to trips taken are often not feasible. In this way, microtransit takes away either cost or travel time burdens for this vulnerable group and on average only adds a few minutes or one dollar to their ride.

Another potential user group is a higher-income, choice-rider group, which was also discussed in Section 5.1.2. In terms of costs and time, there is no motivation for this group to choose microtransit over their car: the variable costs for taking the ride with the car are lower and the travel time with microtransit is longer. This group still chooses microtransit occasionally mainly because of other factors, like convenience.

Overall this shows us that for transit-dependent riders microtransit is an alternative that has the upper hand when competing with both public transit, walking, and ride-hailing in the area. When competing for choice-riders microtransit can attract riders by being a convenient mode of transit and by limiting the additional travel time compared to cars.

	Time	**Costs**		**Other**		
Replacement mode		**Fixed**	**Variable**	**Convenience**	**Reliability**	**Safety**
Public Transit	Slower	Same	Slightly lower	Lower	Similar	Similar
Taxi/ Ride-hailing	Faster	Same	Higher	Similar	Similar	Similar
Private Cars	Faster	Higher	Slightly lower	Lower	Higher	Higher
Walking	Significantly slower	Same	None/ lower	Lower	Higher	Lower

Table 5.2: Summarized comparison of microtransit against alternative modes.

5.3.3 Induced Trips

Besides shifting the distribution of demand amongst existing transport modes, microtransit can also induce new trips. Induced trips are trips that would have not been taken were it not for the availability of microtransit. In the survey, 27% of users indicated that they would not have taken their trip if microtransit were not available. Though this is a minority it is considered a large part of the total trip base, because these are trips that can be confidently considered as induced by microtransit. The fact that 71% of trips did not have a public transit alternative especially pushes the idea that microtransit induces many trips amongst groups with (low) access to a vehicle.

5.3.4 Summary

As summarised Table 5.2, microtransit offers a significant improvement in costs and travel times for the transit-dependent population. For those that are choice riders, microtransit can still be the preferred mode of transit because of its convenience. For the studied area microtransit trips seldom had a feasible public transit alternative and walking counterparts of trips were also mostly unfeasible. Microtransit is slower than the modes private car and ride-hailing but the difference is not extreme, especially when excluding wait and walking time from the equation and taking into consideration that most trips are around 15 minutes long. There is a great potential for redistribution of cost, travel time, and 'other' through the addition of microtransit to the travel mode mix. Additionally, microtransit also seems to induce new trips, especially for transit-dependent riders.

5.4 SYNTHESIS: ACCESSIBILITY TO OPPORTUNITIES

In this section, we aim to answer the research question: 'How (much) can the distribution of accessibility to opportunities be shifted by the addition of microtransit as a mode of transport?' As discussed previously, microtransit as an additional mode of transit can decrease costs and travel time for reaching opportunities and therefore increase overall levels of access. In this section, we solely consider its travel time impact. We combine this impact with an analysis of several specific subgroups of the population, such as low-car ownership and low-income groups as well as an analysis of the spatial allocation of the access benefits, and an analysis of how equally access and benefits of microtransit interventions are distributed amongst the entire population. This enables us to get significantly closer to answering the main research question: 'What are the access equity implications of microtransit services in urban environments?'

5.4.1 Microtransit Travel Time Estimation

Based on the comparison of travel times in Section 5.3 a scenario is employed in this analysis where microtransit is assumed to be 1.3x slower than a car. This excludes the waiting time of approximately 15 minutes because it is assumed that that wait time is communicated to the rider and since the pick-up is usually a home or familiar location, the rider can adjust their plans accordingly. Walking time is also excluded for personal car use to create a more equal comparison between the two.

The entire metropolitan area of Minneapolis-St. Paul is considered for the analysis of jobs, shops, and healthcare facilities' accessibility. The area is demarcated by the 7 counties of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott and Washington. However, microtransit can only reach within the bounds of its service areas whereas cars and public transit can reach far beyond that. This creates a dynamic where microtransit regularly reaches the maximum amount of points of interest that are available in the service area.

It is important to note that the combination of microtransit and public transit as a transit option does not include riding microtransit to a major public transit corridor to make a public transit passage there (the first and last mile approach), a possibility which would probably greatly increase the number of points of interest reachable within a given time with microtransit. This kind of combination of modes is too complex for the current analysis. Instead, only the fastest alternative of the two modes (microtransit or public transit) for each combination of origin and point of interest is considered, per Equation 4.3.

5.4.2 Scenarios

Several scenarios are used for calculating the impact of the cumulative access to each service type and the aggregated access scores:

- Scenario 1: in this scenario the part of the population that has zero or 1 vehicle in their household (approximately 30%) is taken as being the group whose access level is determined by public transit and/or microtransit.
- Scenario 2: in this scenario, only the part of the population that has zero vehicles in their household (approximately 3%) is taken as being the group whose access level is determined by public transit and/or microtransit.
- Scenario 3: in this scenario, the access level of the entire population is determined by public transit and/or microtransit. This scenario is used to show the (in)equality of distribution of the transit services.

Scenario 1 is used for the individual cumulative access scores. Scenarios 1-3 are used for the aggregated access scores.

5.4.3 Cumulative Access

The cumulative access within 30 minutes and 1 hour was calculated per Equation 4.6.4 for the potential travel modes car, public transit, microtransit and a combination of microtransit and public transit. Overall, the results for each service type are quite similar: access levels do drastically increase when adding microtransit as a transit mode, but microtransit is never able to reach the level of access to is enabled by (personal) car use.

Jobs

Figure 5.20 shows the average amount of jobs that residents of service areas A and B combined can reach in 30 minutes or 1 hour by different modes of transit. This plot demonstrates that though microtransit cannot approximate the level of access enabled by cars, it does provide a significant improvement from the number of jobs that could be reached with the public transit network.

Seeing these results, it is also easy to imagine how many more jobs could be reached if microtransit were used in conjunction with public transit: taking residents to major transit corridors from where they can continue their trip into the metropolitan center, where a much higher concentration of jobs is available. This bridge to the public transit network that does link the suburbs to the city center could not be included in this analysis but could only positively impact the number of jobs that microtransit riders can reach.

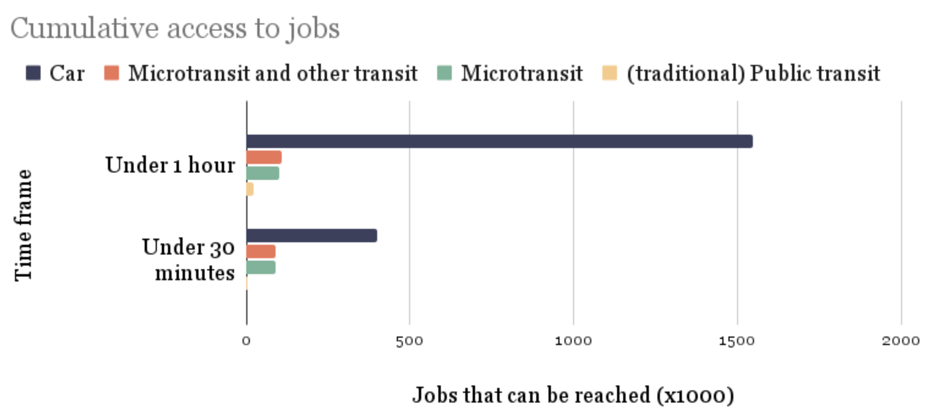
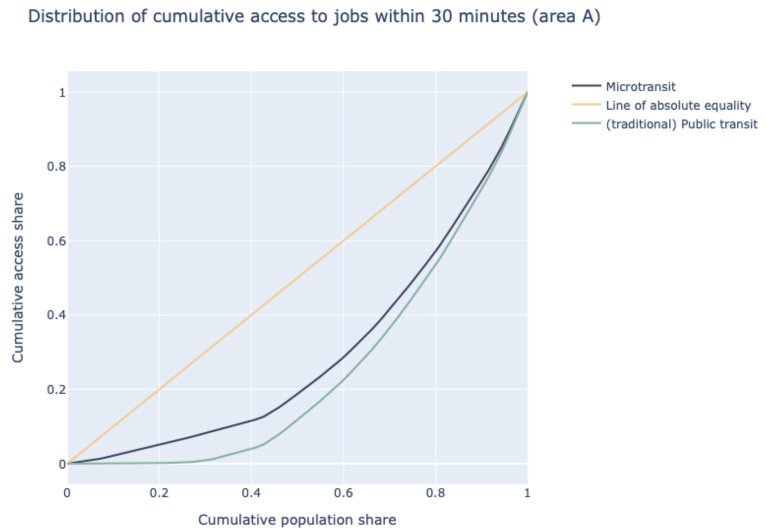
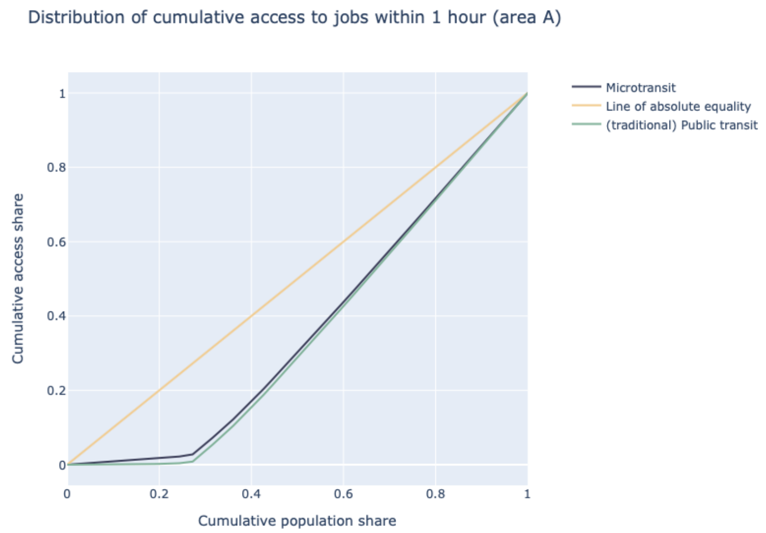


Figure 5.20: Cumulative access to jobs for different transit modes and time frames, both service areas combined.

Figure E.9 shows how the distribution of jobs available is shifted when microtranist is added to the transport mix. The shift seems quite minor on the graph but that is partly because the difference only impacts that part of the population that has no or one vehicle available to their household, which is already a vulnerable group in terms of transport. The distribution is shifted enough to be significant for jobs reached in 30 minutes but not in 1 hour. This demonstrates the effect that microtransit can reach all jobs or places within the area in between 30 minutes and 1 hour and therefore is not able to add extra access for this group after that points. Therefore, the redistribution of access for the 1 hour timeframe is not significant anymore. The redistribution is small but it does make a lot more jobs available to this specific group. Since the remainder of the cumulative access results are very similar, no more Lorenz curves will be provided in the main text, they can be found in the appendix (Appendix E)



(a) Jobs reachable within 30 minutes, the Gini coefficient is shifted from 0.498 to 0.407



(b) Jobs reachable within 1 hour, the Gini coefficient is shifted from 0.294 to 0.274.

Figure 5.21: The Lorenz curves showing the distribution of cumulative access to jobs within 30 minutes and 1 hour for service area A.

Shops

Before the microtransit service, 24% of the population lived in an area from which no shops could be reached within 30 minutes without a car. With the microtransit network, this was brought down to 0. As shown in Figure 5.22 cars can still reach many more shops but microtransit, again, enables a minimum level of access that could not be reached with traditional public transit. Again, the Lorenz curves for shops are similar to those for jobs and show highly significant redistributions for within 30 minutes but not for within 1 hour.

Figure 5.22: Cumulative access to healthcare facilities for different transit modes and time frames, both service areas combined.

Healthcare Faciltiies

Concerning healthcare facilities, it should be reiterated that a minimum level of access is crucial. Without microtransit, 88% of the population lived in an area from which no healthcare facilities could be reached within 30 minutes without a car. Due to 3% of the population not owning a car, this means that 2.5% of the population was not able to reach a healthcare facility within 30 minutes. Microtransit almost completely eradicates this problem, with only 0.04% of the population still not being able to reach a healthcare facility within 30 minutes. When evaluating healthcare facilities reachable within an hour this problem is already alleviated quite a bit, with 0.3% of the population not being able to reach a healthcare facility within one hour without microtransit and the entire population being able to reach one with the microtransit service.

Figure 5.23 also shows how many healthcare facilities on average the residents of the areas can reach. The improvement through microtransit, especially within the 30 minutes time frame, is very clear. The Lorenz curves for this point of interest show a similar distribution as those for jobs and shops and can be found in Appendix E. Again, the difference in distribution for under 30 minutes is significantly shifted by the addition of microtransit to the transit mix but the distribution of access within 1 hour is not shifted to such an extent.

The cumulative access to jobs, shops, and healthcare facilities overall greatly increases when riders can use microtransit, as demonstrated by Figure 5.20, Figure 5.22 and Figure 5.23. This supports one of the two dimensions of distributive justice for access: microtransit enables a minimum standard of access for that part of the population that is vulnerable: those with low access to cars. The change in the distribution of cumulative access within 30 minutes is significant, but that same change for the 1 hour timeframe is often not, since the microtransit service reaches the outer bounds of the service area and cannot reach additional points of interest anymore.

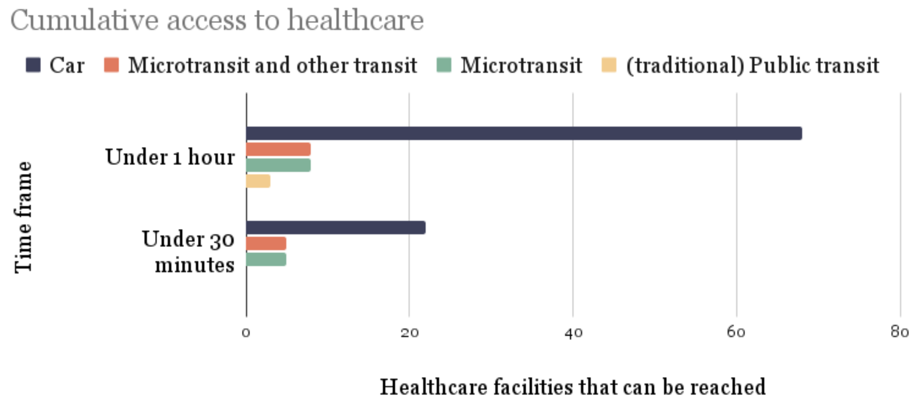


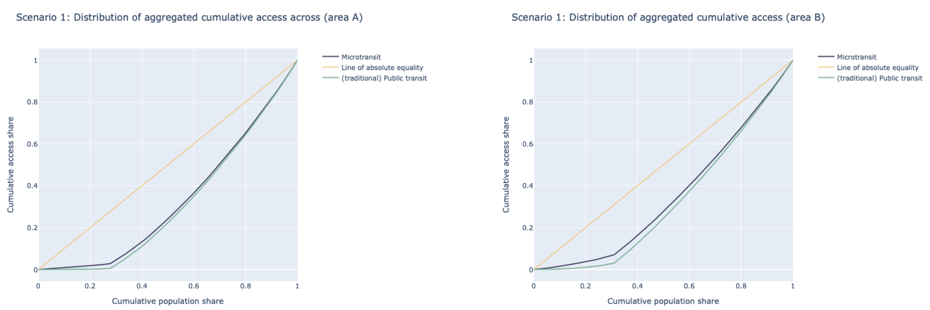
Figure 5.23: Cumulative access to healthcare facilities for different transit modes and time frames, both service areas combined.

5.4.4 Aggregated Access

Equation 4.4 showed how the cumulative access to jobs, shops, and healthcare facilities can be aggregated to one accessibility measure. For this metric, the access levels for jobs within one hour, healthcare facilities within one hour, and shops within 30 minutes are used. This decision was made based on the study by Iacono et al. [2008], conducted in the same case study region which shows overall patterns in how long individuals are willing to travel for specific activity types.

The Lorenz curves in Figure 5.24, Figure 5.25, and Figure 5.26 show for the redistribution of access in the case study areas for all three scenarios. For the first and third scenarios, clear redistributions can be observed. For the second scenario, the redistribution is less clear due to a smaller group being impacted by the change in access. Figure 5.26 also clearly shows how much more equally the benefits of the microtransit service are distributed compared to (traditional) public transit. The distribution of public transit access is distributed very unequally across the area at an Gini of 0.477-0.684. This distribution is caused by the spatial concentration of public transit corridors. A major part of the population is not able to reach these corridors while others can experience major access advantages from them. Microtransit access gains are equally distributed because microtransit rides can be taken from anywhere in the case study area.

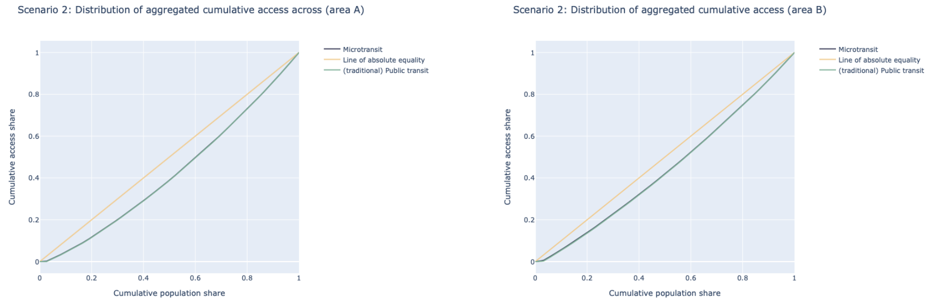
The equal distribution of microtransit-enabled access, in combination with the knowledge that microtransit reaches many vulnerable groups, demonstrates that even when microtransit is not able to alleviate existing inequality altogether, it is an inclusive and fair additional transit option.



(a) Area A, the Gini coefficient is shifted from 0.372 to 0.346.

(b) Area B, the Gini coefficient is shifted from 0.347 to 0.302.

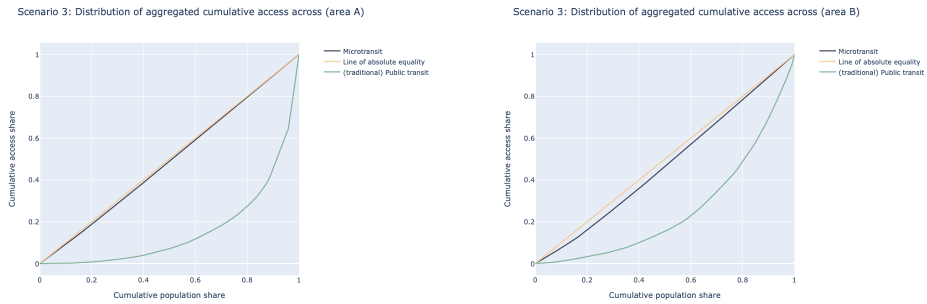
Figure 5.24: The Lorenz curves showing the aggregated access distribution, scenario 1.



(a) Area A, the Gini coefficient is shifted from 0.156 to 0.154.

(b) Area B, the Gini coefficient is shifted from 0.119 to 0.115.

Figure 5.25: The Lorenz curves showing the aggregated access distribution, scenario 2.



(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.

Figure 5.26: The Lorenz curves showing the aggregated access distribution, scenario 3.

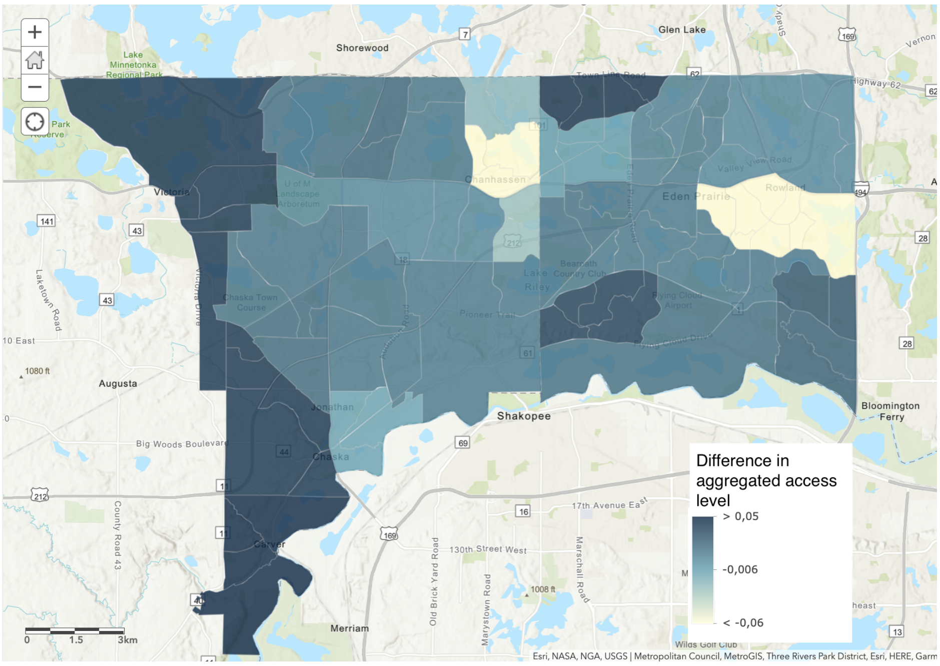
5.4.5 Distribution of the Benefits

A major factor in evaluating how equitable a policy is is quantifying how vulnerable groups benefit from that policy. Here low car ownership and low-income groups will be considered as these vulnerable groups. Additionally, the spatial distribution of (benefits of) microtransit will be shown and discussed.

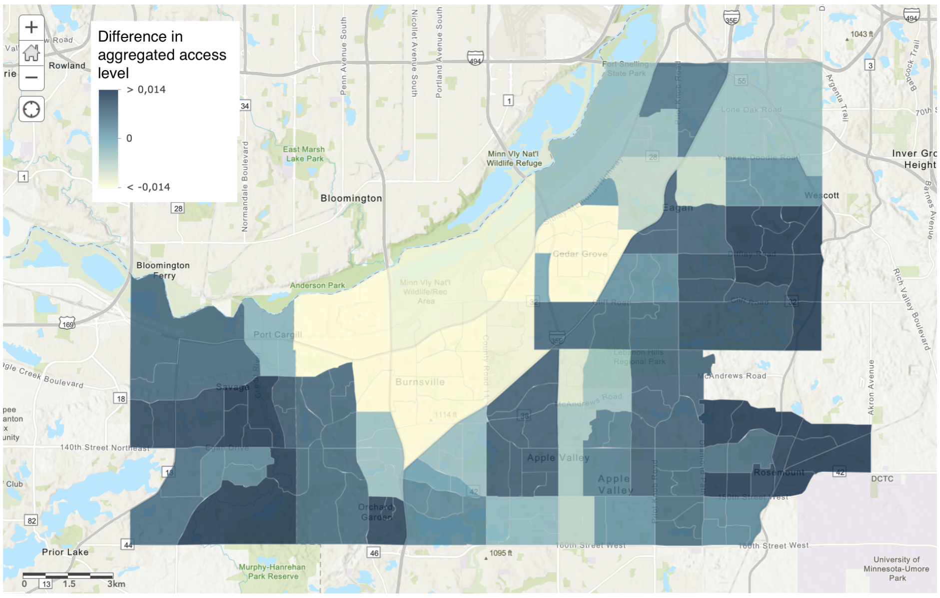
Car ownership: in this analysis it was clearly demonstrated that the group with low car ownership is the one that can benefit the most from microtransit interventions since they are most likely to use microtransit to reach a minimum level of access, of which the clearest example is the increase in access to healthcare facilities, demonstrated in Figure 5.23. As shown in particular in Figure 5.24 and Figure 5.26, microtransit poses an alternative to public transit options whose benefits are significantly more equally distributed amongst the population. Overall, groups with low car ownership and high transit dependence benefit by far the most from the microtransit service.

Income: no clear patterns could be identified in neighborhoods with lower or higher income experiencing more or fewer benefits of microtransit. However, it is known that income level is highly correlated with car ownership. Therefore, it is probable that the benefits for the part of the population with low levels of car ownership will overlap with the benefits for the low-income population.

Spatial: there are also spatial patterns that can be identified in who benefits most from the microtransit service. Figure 5.28 displays per destination type which areas benefit most from microtransit compared to public transit. The spatial patterns per destination type are quite distinct. The distribution is dictated by a combination of the location of the points of interest and the public transit corridors. Particularly for the number of jobs that can be reached within an hour, it can be observed that the eastern top of service area A does not gain that much access (relatively) from the microtransit interventions. This is because a transit corridor is located here leading to many more jobs in the city center. For shops and healthcare, similar patterns were identified. The relation between benefits and location of transit corridors is most prominently shown in Figure 5.27 which shows the spatial distribution of the aggregated access level. Fewer benefits are observed for both areas in the regions where there are major public transit corridors to the center of the metropolitan region, where many more jobs, shops, and healthcare facilities can be found.

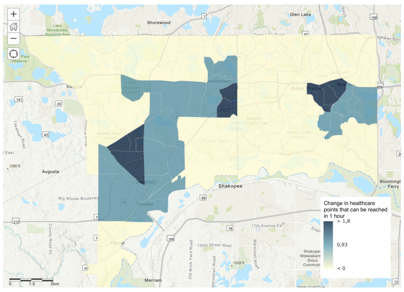


(a) Area A.

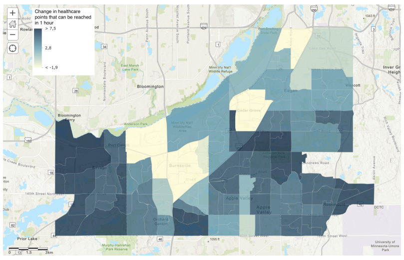


(b) Area B.

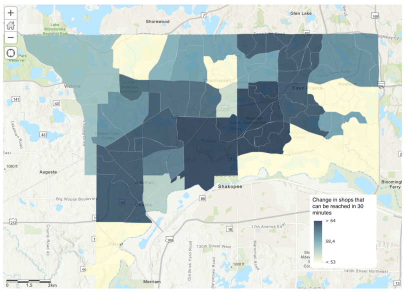
Figure 5.27: The spatial distribution of the benefits of microtransit for aggregated access



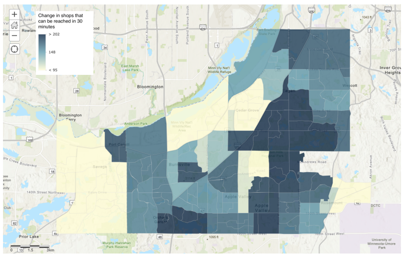
(a) Healthcare facilities reachable within 1 hour, area A.



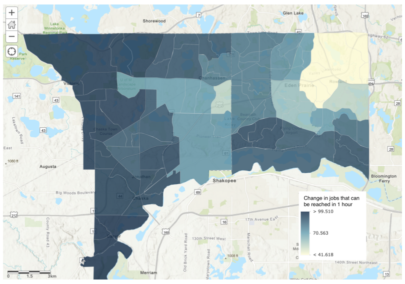
(b) Healthcare facilities reachable within 1 hour, area B.



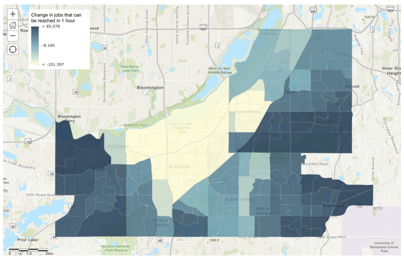
(c) Shops reachable within 30 minutes, area A.



(d) Shops reachable within 30 minutes, area B.



(e) Jobs reachable within 1 hour, area A.



(f) Jobs reachable within 1 hour, area B.

Figure 5.28: The spatial distribution of the benefits of microtransit for different types of access.

5.4.6 Summary

In conclusion: based on this analysis it is clear that microtransit can enable many residents to reach a minimum standard of access without a car. The extent to which microtransit alleviates the existing inequality in the distribution of access in this area is limited, though significant. The car is still a faster alternative that can reach outside the bounds of the service area, therefore always reaching more points of interest. However, it is positive to observe that the access enabled by microtransit is very fairly distributed across the population, and most benefits are felt by those with low car ownership. Spatially the distribution of benefits is largely dependent on which areas have a poor connection to the public transit network and which areas already possessed a high concentration of points of interest.

6 DISCUSSION

This study showed how microtransit impacts access equity through the individual, land-use, and transport components and in particular by redistributing overall access levels to jobs, shops, and healthcare facilities. The results indicate that microtransit can reach vulnerable transit groups: low-income, non-white, elderly, and disabled riders. This contradicts current findings on microtransit and ride-sharing ridership, which present a profile of younger and wealthier riders [Lazarus et al., 2021]. This difference might be caused by the integration of the studied microtransit services with the traditional public transit provider as well as the curb-to-curb nature of the service. Microtransit also reaches a combination of choice riders and transit-dependent riders, with choice riders forming the majority, probably because of the overall demographic of the studied area. Haglund et al. [2019] showed that microtransit mostly replaced the car but also occasionally replaced walking and cycling. In this case study, a similar pattern is observed where public transit and walking counterparts of microtransit rides are often unfeasible and therefore microtransit mostly takes over demand from cars and ride-hailing or induces trips amongst low-car-ownership groups.

Palm et al. [2021] surveyed the pilots with new mobility technologies, including microtransit, and failed to find any explicit equity potential of microtransit. This study pleads that microtransit does have great access equity potential. By reaching vulnerable groups, connecting them to commercial areas, and providing a cheaper alternative to ride-hailing and a much faster alternative to public transit and walking, microtransit can alleviate access inequity. Additionally, the access analysis made it clear that microtransit does enable residents with no or limited access to a car to gain a minimum level of access and can significantly shift the distribution of access. The growing microtransit has the potential to shape transit for the better.

This research is one of the first of its scope on the relation between microtransit and access equity. It challenges the existing literature on ride-sharing, microtransit, and ride-hailing by providing a case study in which microtransit is shown to have a positive impact on accessibility and reaches vulnerable groups to an extent that has not been presented in other scientific works. Additionally, this work highlights how the suburban environment and its challenges in particular fit the characteristics of microtransit. Besides showcasing the relation between microtransit and access equity this study also provided a framework for conceptualization and operationalization of the relation between a novel transit form and access equity. This framework could be applied to other transit forms, for example, ride-hailing services or shared vehicles, that are on a rise in cities around the world.

6.1 THEORETICAL LIMITATIONS

A few theoretical limitations to this work have to be presented alongside its major findings.

- The conceptual model that was highlighted in Chapter 3 provided a framework for this analysis. However, not all dimensions and relations could be studied in detail. One of the relations within the transport component that could not be studied is the relationship between public transit and microtransit. This relation entails the possibility for passengers to take microtransit rides from their home (or other origin location) to a transit corridor and then continue their journey by taking a traditional public transit mode. This way of traveling is also encouraged in the service area by offering reduced fares for combined trips. Due to the complexity of simulating combining several transit modes, this option was not included in this study. However, it can be assumed that the inclusion of this possibility would only improve the access levels and access equity in the studied areas because it brings more rides into the range of possibilities for the population.

- Next to this internal relation in the transport component, the temporal component of the accessibility model in Chapter 3 and the competition for opportunities (in particular jobs) was left out of this research due to the complexity of retrieving and handling this data. Though this component might influence the actual access to services and amenities, it is too complex of a mechanism to include in this initial work on the topic.
- The accessibility analysis solely focused on travel time as the factor determining the selection and 'costs' of a transit mode. Reliability and other factors of choice were only shortly addressed. Though other factors impact travel mode selection, travel time was selected as the sole indicator for the accessibility analysis because it is quantifiable and enables a smooth operationalization of the cumulative access measure. Costs would have created a distorted picture of access since, in the studied area, the traditional public transit and microtransit systems work with one-off fares.
- It was also assumed that those that did have convenient access to a vehicle (households owning more than 1 vehicle) always would opt for a personal car ride since it was the fastest option. This omits the group of choice riders from the accessibility analysis, even though they do experience added transit benefits from the convenience of microtransit. This group also makes up a significant portion of the rider base and it is considered a positive side-effect of microtransit that public transit becomes an option for those living in the suburbs, even when they are not transit-dependent. However, since this group can still always opt for the more efficient alternative of a personal car ride, it is logical that the benefits that they experience are not included in the accessibility analysis.
- In this study the supply of microtransit rides was considered infinite for the accessibility analysis. It was not considered that if all these rides would be taken that this would have a thorough impact on wait time, travel time, and effectiveness of the network. This was considered acceptable because of the scope of the current analysis and the fact that the current networks have been able to handle extensive growth in recent months and years.

6.2 METHODOLOGICAL LIMITATIONS

Besides theoretical limitations, there are also some methodological limitations to this work.

6.2.1 Data

The following limitations can be identified with regard to the data used:

- Several data sources were used, with data spanning from 2016 up until 2022. 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 jobs availability and infrastructure.

- During this 2016-2022 time frame a major pandemic swept across the world, including this area. This decreased the number of trips significantly though trips steadily rose again afterward. There might be a difference in transit use before and after the pandemic, which limits the comparability of data from the transit on-board survey and the microtransit surveys.
- Due to privacy regulations, there was no user ID present in the microtransit ridership data. This made it impossible to match data and uncover individual travel patterns that might skew the data to any extent.
- There were missing data on wait time as well as on the difference between requested and realized pickup time. These values were imputed with average values.
- The survey groups were limited for both the transit on-board survey and the microtransit survey. Both survey samples are still of decent size with over 1000 responses. The microtransit survey outcomes were also roughly consistent over time which instills trust in the representativeness of the studied sample.

6.2.2 Methods

The following limitations can be identified with regard to the methods employed:

- The case study approach, in nature, makes it difficult to generalize results. Therefore, this work does not plead to do so. Instead, there are many similar cases to be found across the U.S.A. in particular where suburban environments face limited public transit networks and consider microtransit as a potential solution. These cases are considered similar enough in the dimensions of land-use, socio-economic development, and distribution of services and jobs that the insights from this research can be applied to them. The policy recommendations that will be given in Chapter 7 have also been generalized to some degree to ensure that they can be applied to a variety of cases.
- The interviews conducted with senior employees of the (micro)transit providers might be biased and leading due to them being conducted by the author herself and the sample size being limited. This is a natural limitation of interviews. However, the conclusions drawn from the interviews were often supported by quantitative data, solidifying these findings nevertheless.
- The trip planning software that was used, OTP, faced some computational difficulties such as running slow and struggling with processing the large volume of infrastructure and GTFS data. For this reason, the analysis was scoped down to feature only one GTFS file per year and to limit the infrastructure data to a sample of solely the service area for the comparison of travel times within the area boundaries. A more precise and computationally heavy approach would have led to more accurate results, but because the changes in transit schedules and infrastructure were considered limited this was not considered problematic.
- The cumulative accessibility measure was used. This measure has a strong communicative value but is considered less theoretically sound than the gravity-based or utility-based measure. However, recent research has demonstrated that the cumulative and gravity-based measures are highly correlated. Therefore, the choice for cumulative accessibility to increase communicative value was justified.

- Only jobs, shops, and healthcare facilities were considered as points of interest for the accessibility analysis. Many more points of interest could have been identified and studied to provide a more accurate aggregate access score. But again, some parts of the analysis had to be left out to balance the scope with theoretical soundness. In this case, 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 aggregated access measure was calculated based on specific weighings of the different studied destinations as well as specific time frames within which points of interest could be reached. These cut-off points were based on quantitative data from the same case study area. The weights were based on reviewed literature. However, there can be a wide variety in how much individuals value access to destinations, for example, a chronically ill individual might value access to healthcare facilities much more than access to shops. Still, a generalized approach is necessary and acceptable for this kind of aggregated analysis.

6.3 FUTURE RESEARCH

To further extent the knowledge on microtransit and access equity, and overcome the limitations of this study, the following future research directions are suggested:

- This thesis specifically focused on a suburban environment. In terms of the (historical) position of public transit and the degree of urban sprawl, these areas are very different from urban (core) and rural environments. Therefore the insights from this study should not just be applied in those contexts. Instead similar analyses on the relation between microtransit and access equity should be conducted for urban (core) and rural environments. Along the same lines, other suburban environments with distinct characteristics, such as lower average income and car ownership, could be studied.

- The group of choice riders that uses microtransit is regularly discussed in this study. This group and their distinct motivation for choosing microtransit over the (personal) car should be further studied. Though this group's access level is not considered to be impacted by microtransit interventions and the group is not considered vulnerable, there is a potential for significant sustainability gains if they do use microtransit instead of (personal) cars. Remaining attractive for choice riders could therefore be an interesting goal that might alleviate congestion and environmental damage.

- The relation between microtransit and public transit and the ability of microtransit to solve the first and last mile problem should be further investigated. As mentioned before, the mechanism of using microtransit to reach public transit corridors could greatly increase access levels. From the interviews, it seems that this possibility is employed to a smaller extent than expected but the reason for this is unclear. Further investigation of whether and why people do not make use of this option to a great extent yet and how it might impact their transit experience and level of access if they would, will potentially greatly increase the impact of microtransit.

- The traffic congestion and sustainability impact of microtransit was considered to be outside of the scope of this research but it is an important topic for further investigation. Microtransit has a smaller traffic congestion impact and carbon footprint than ride-hailing or personal car use but it has a larger impact than public transit and walking. Investigating this impact relative to other modes is crucial to enabling a sustainable transit system.

- In addition to the four components of the conceptual model of access studied in this research, Lucas [2012] suggests a fifth cognitive dimension to access. This component concerns the ability of individuals to interact with the transport system. Studying this dimension could provide for interesting future research on the (mental) barriers that individuals experience for interacting with microtransit.

7 CONCLUSION

The main question that this research aimed to answer was: 'What are the access equity implications of microtransit services in urban environments?' After studying all the components of the relation between microtransit and access equity in the case study area, a few conclusions can be drawn:

- **Microtransit can reach vulnerable rider groups:** low-income, non-white, elderly, and disabled individuals use the transport mode. Women and men are equally represented in the sample of survey respondents. Microtransit thereby fulfills the role of serving communities that traditionally struggle to use public transit.
- **Microtransit majorly connects residents to commercial centers and fits the suburban environment well:** by creating a new, flexible form of public transit in an area where it was previously lacking microtranit fits the studied suburban environment extremely well. Land-use analyses showed that there are significant hotspots to be identified for the microtransit rides in the studied areas and that these overlap with the retail and commercial centers in terms of land-use.
- **Microtransit is a great addition to the transit mix for those that do not have access to a car:** Microtransit offers a significant improvement in costs and travel times for the transit-dependent population. For those that are choice riders, microtransit can still be the preferred mode of transit because of its convenience.
- **Microtransit shift the distribution of accessibility significantly and enables many residents to reach a minimum level of acces:** it was demonstrated that microtransit can get many residents to a minimum standard of access without a car. The extent to which microtransit alleviates the existing inequality in the distribution of access in this area is limited but significant, majorly because the car is still a much faster alternative that can reach outside the bounds of the service area. However, access enabled by microtransit is very fairly distributed across the population, and most benefits are felt by those with low car ownership and those that spatially did not have convenient access to public transit before.

All in all, it can be concluded that microtransit positively impacts access equity in the case study environment and has the potential to do the same in other areas.

7.1 POLICY RECOMMENDATIONS

Based on the findings of this thesis a few policy recommendations can be made. These recommendations are targeted at policy-makers and transit agencies.

7.1.1 Policy-makers

The on-demand transit market is growing fast [Foljanty, 2021]. The rise of a new technology and initial findings on the positive urban impact of that technology can cause policy-makers to feel like they should quickly adopt it. A few recommendations are given here for policy-makers, be it at a state or local level, that are interested in adopting microtransit:

- It is crucial to carefully consider whether microtransit is the right fit for the area you are governing. The following quote from one of the interviews with the transit providers clearly illustrates this: *'I talk a lot about [microtransit] and give a lot of presentations on it and [..] when I talk to other transit systems they always are like well this is working for you, it's awesome, we wanna do it. And I say it's not necessarily gonna work, it depends on your use case at the end of the day. Each use case is unique.'* For this research, a case study was conducted in a suburban environment. This environment seemed to be a good fit: the challenges of the contemporary suburban environment (suburbanization of poverty, lack of public transit, urban sprawl, and car-centric policy) can be partly resolved by public microtransit services that can serve a low-income, transit-dependent demographic, don't require extensive infrastrucuture, and can be flexibly employed. This research does not provide evidence that the same natural fit will occur in an urban (core) or rural environment.

- Additional factors that could be taken into consideration when considering building a microtransit service are the income and car-ownership level of the community it aims to serve. Communities with low income and car ownership should be prioritized because they gain the highest benefits from microtransit and are vulnerable transit groups. Other vulnerable transit groups such as the elderly, the disabled, racial minorities, and women should also gain specific attention in implementing microtransit systems. One way to do so is to ensure legal standards for comfortably transporting disabled people are met and the technology through which rides can be booked is accessible for all.

- Instead of creating or taking on offers by new microtransit providers it might be wiser to formulate plans for a microtransit service in collaboration with the existing public transit agency. This has a few advantages: (i) this agency already has information on which routes are and are not performing well in the current public transit system, (ii) this agency also has the 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 the elderly, to make use of the microtransit system.

- When building a microtransit network to alleviate access inequity and potentially soften the effects of suburbanization of poverty it is key to track this impact. If the impact is not tracked, it will be impossible to quantify how the network is performing and how it can adjust to increase its impact. In this thesis, an extensive analysis is presented to track many aspects of access equity and create an overall picture of the impact of microtransit on access equity. Understandably, such an analysis is not always possible. To gain quick insights into the performance and impact of the microtransit network a few smaller analyses can be conducted: (i) surveys can be conducted to track the average income, disability status, race, gender, and age of riders, demonstrating the extent to which the service is reaching vulnerable rider groups, and (ii) microtransit trips can be sampled and processed with a trip planner to check travel times compared to cars, public transit and walking alternatives, which can give insights into the competitive value of microtransit as well as prevent that it is replacing the more sustainable alternatives of public transit and walking.

7.1.2 Transit Agencies

Providers of public transit are observing shared mobility services like Uber and Lyft flip the transit market and take over part of their rider base. Microtransit might provide these transit agencies with the perfect balance between ride-hailing and public transit, enabling riders with a lower income to use a service that is flexible and easily accessible. But how can transit agencies smoothly build a microtransit service and how can they ensure their services have a positive impact and are effective? Some recommendations are given here:

Riders

- In this thesis two main rider groups are identified: transit-dependent riders and choice riders. Public transit agencies might traditionally have encountered more transit-dependent riders. As shown in the case study, microtransit might attract more choice riders to the public transit system. It is important to keep in mind the differing interests and values of these two user groups. Transit-dependent riders might use microtransit several times a week, they especially need microtransit to be faster than walking and public transit and choose it over ride-hailing options for its price. Choice riders on the other hand choose microtransit as an occasional replacement for their car and are more driven by its comfort and ease of use, they might also steer away from microtransit if it becomes too slow compared to their (personal) car. Balancing price, speed, comfort, and ease of use is, therefore, key to serving both user groups but a decision can also be made to predominantly focus on one.

- It is often hard to define what is truly the right audience for a service. However, here access is considered from the perspective of equity. Therefore there is a focus on the findings mentioned in Chapter 2 regarding what that right audience is. To reiterate: Pereira et al. [2017] states that we should take into account (i) a minimum standard of accessibility and (ii) a reduction of inequality of opportunities and therefore a prioritization of vulnerable groups. For the case studied here, this means initially focusing on those vulnerable transit groups mentioned before and those areas that have limited convenient access to the public transit network.

- To reach certain vulnerable groups it is important to make the microtransit service itself accessible. Microtransit already is more accessible to the physically disadvantaged through being a curb-to-curb service, minimizing walking time. Additionally, compliance with (national) standards for transporting disabled riders and ensuring that the technology used for booking trips is easily accessible for anyone are two key factors to ensuring accessibility.

Network

- Pay-offs might have to be made between the traditional public transit network and the microtransit network. Microtransit might be a reason to accept certain cut-downs on unpopular or ineffective routes. However, microtransit is a less sustainable and cost-effective alternative to public transit. It's therefore key to prevent the usage of microtransit on routes that could also be effectively operated with a fixed route service, while keeping in mind the interests of the riders.

- Microtransit has shown itself as a deeply local service. It serves only a limited area and though that can be seen as a disadvantage it is also part of its strength as it enables fast rides and effective scheduling. So when expansions are made, they should be targeted at areas with commercial centers (opportunities) or low car ownership (likely riders). Specific rides to areas of interest, such as an airport, large mall, or popular place of employment, might be considered as an option as well.

Collaboration and competition

- Creating joined fares and one-day tickets with which riders can ride both the microtransit and the (traditional) public transit network might be a great way to encourage the first and last mile application of microtransit and thereby increase the access levels of its riders even more.
- For service providers that want to track their competitiveness with other transit modes it can be smart to track travel time compared to competing modes: (personal or ride-hailing) cars, public transit, and walking. Comparing microtransit to these modes can be done (i) to prevent taking on trips that could have been taken with the more sustainable options of walking and public transit, and (ii) to ensure remaining competitive with personal cars and ride-hailing, thereby staying, or becoming, an attractive option for choice-riders.

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A DIAGRAMS

A.1 RESEARCH FLOW DIAGRAMS

The full diagram in Figure A.1 shows the inner process from data, with analysis to results for each research question. This diagram also demonstrates the final steps to the conclusion . The simplified version, also shown in Chapter 4 is shown in Figure A.2.

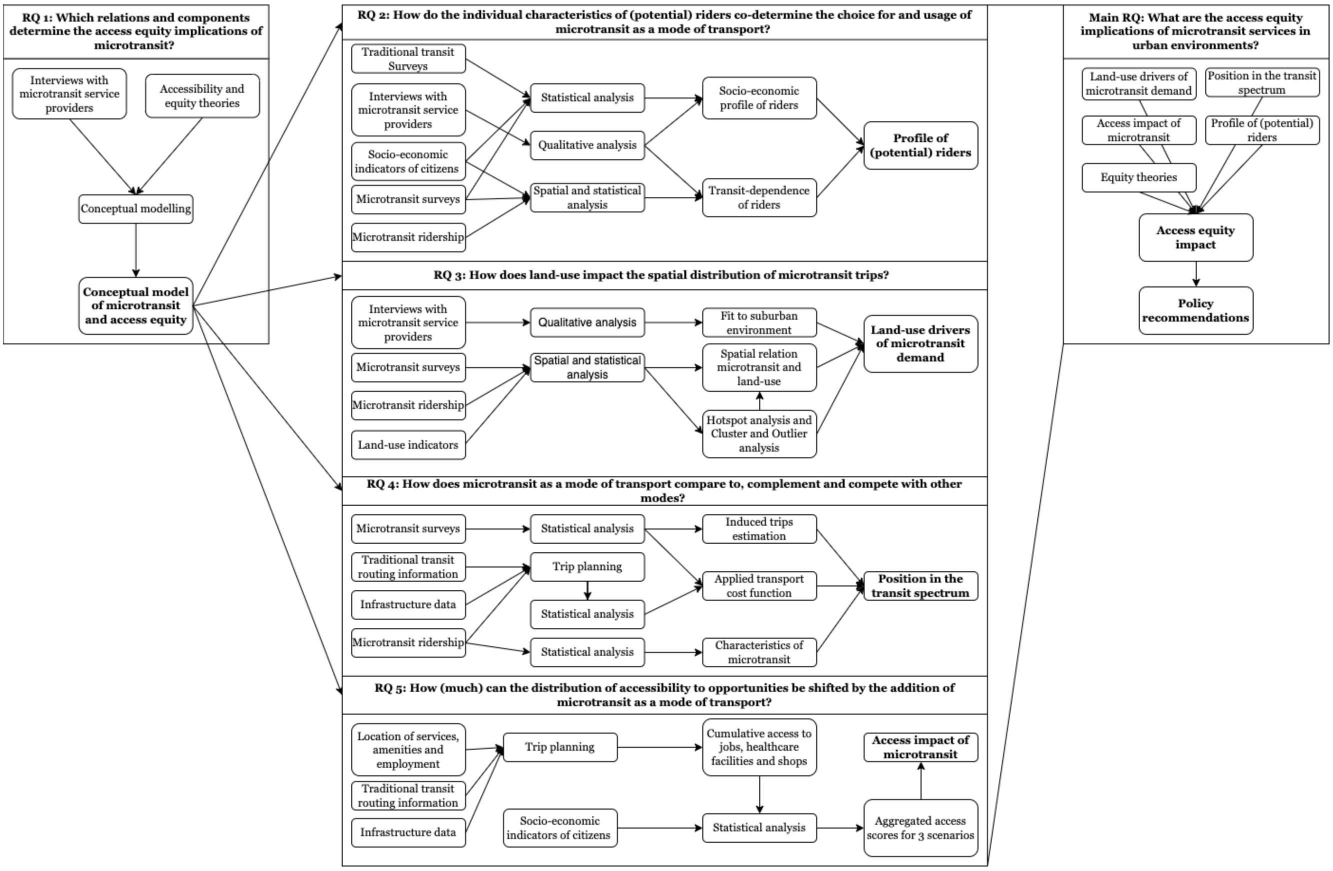


Figure A.1: The extended methodology diagram for this thesis research.

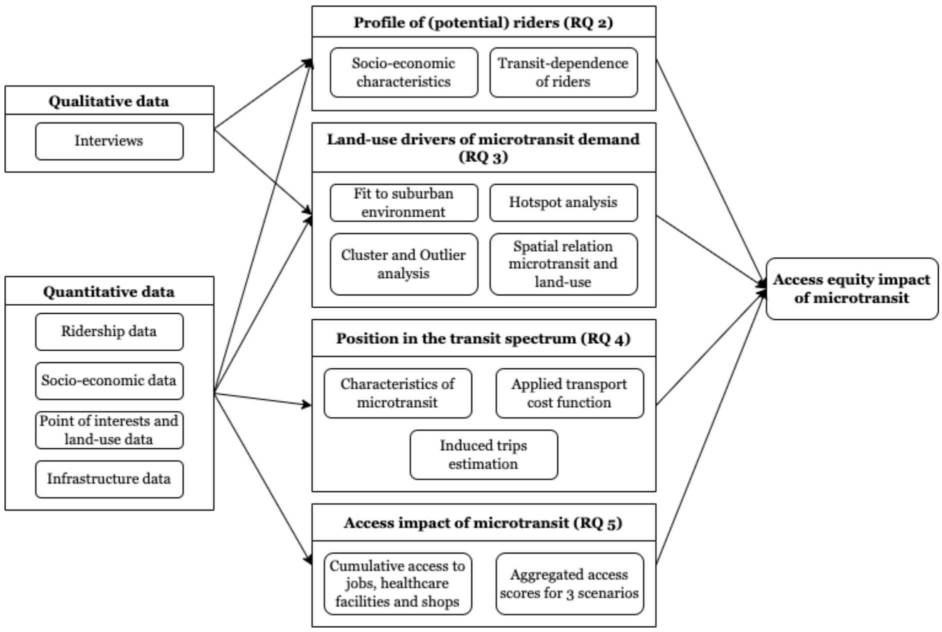


Figure A.2: The simplified methodology diagram for this thesis research.

B SUMMARIES OF INTERVIEWS

B.1 PREPARED QUESTIONS

Goals

- With what goal or objective did you start your microtransit service?
  - (If they had a clear objective:) Did you decide on this goal yourself or together with the municipality/State or another actor?
- Is this still the objective or did this change through time?

Users

- Did you have an envisioned user group for *microtransit service*?
  - (If they had a clear vision) Has this target group changed over time?
  - (If not mentioned already) What are your experiences so far in terms of if you are actually reaching those people?
- Are you undertaking any actions to target these (or other specific) groups?

Interaction with traditional transit network

- How do you see the interaction or relation between your more traditional public transit services and the microtransit network?
  - (If not mentioned already) Is the planning of both services done separately or based on each other?
  - (If not mentioned already) Do you mind or fear that certain parts of that network might be replaced by microtransit?
- How do you see the future of traditional public transit and microtransit?

B.2 INTERVIEW A

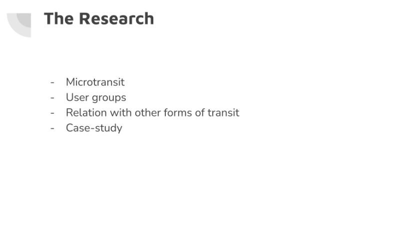
On April 5th, 21:00 Amsterdam Time, an online meeting/interview was conducted with a high-level executive of transit agency A. During this meeting the interviewer (the author), the interviewee (the transit agency senior employee) and a third individual (an employee of the intermediary company coordinating the meeting) talked about the objectives, users and planning of the microtransit services. Below the prepared presentation and a transcript of the conversation can be found.

B.2.1 Prepared Presentation

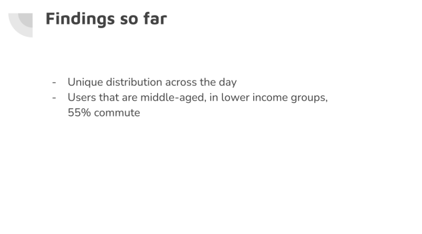
The presentation in Figure B.1 was presented to the interviewees before asking the prepared questions. The slides where the microtransit service name is mentioned are anonymised.

(a) Opening slide.

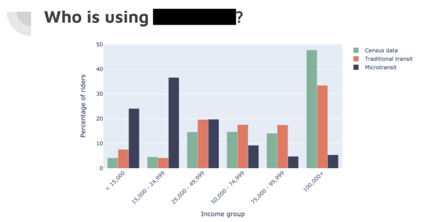
(b) Introduction to the interviewers background and the university.



(c) Introduction to the high-level themes of the research.



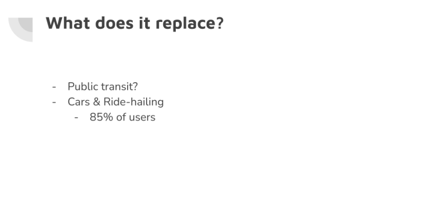
(d) Findings so far on temporal use and socio-economic indicators of users.



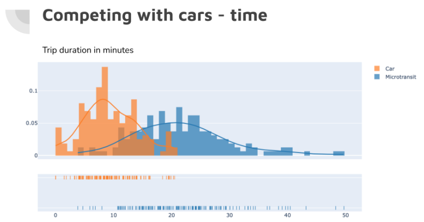
(e) Comparison of income level of microtransit riders, traditional transit riders and local population.

(f) Visualisation of the most popular hotspots in the service area.

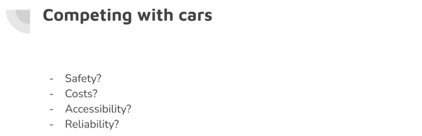
(g) Explanation of what is located at the hotspots.



(h) Findings so far on what transit form users indicate they would otherwise use.



(i) Comparison of travel time with car and microtransit for the most popular routes.



(j) Introduction of a new survey question on why people choose microtransit.

(k) Reflection on the goals of the research and the upcoming findings.

(l) Questions slide.

Figure B.1: The slide deck for the presentation.

B.2.2 Summary

Transit-dependence

- The initial guess was that it would be more of a transit-dependent lower income market, stemming from a lack of any sort of local transit service before.
- There is a vision of getting the microtransit service more in the conscious of choise-riders (given that they live in the area). The provider doesn't expect them to be regular users but having public transit as an option to occasionally replace the car is the goal. The airport service that they run is a good example of this.
- The provider knows that they can't compete with Uber, Lyft or personal cars. Instead the goal is to get it into people's consciousness that you can use transit when you live in the suburbs. This has traditionally not been a reality.

History

- Several attempts have been made to create a fixed routes network, this wasn't productive or efficient. First the provider put al their focus back on the metropolitan/urban area but now that that was completed they focused back on the local service solution.
- Dollar ride and dispatchers were also tried before but those were not efficient, there was no good way to route vehicles and no good user experience.
- The provider also tried one-off suburban local fixed route services, this would serve the demand but only at a fixed time and a fixed route which does not fit the suburban land-use environment (also because of the size of the area).
- Late 2000's early 2010s: the provider started talking internally about having a service like Uber of Lyft. With efforts of staff and board and because the communities asked for a working transit system, it worked out pretty fast (2015) and they became an early adaptor of microtransit. Spare came in in 2019 because the service was growing fast and the software was not working well enough to keep up.

Neighborhood

- The community is relatively affluent, many households own several cars (2-3).
- Transit is an afterthought, many people barely know it's an option.

Collaboration with the state

- Service provider A is a joined powers arrangement between Eden Prairie, Chanhassen and Chaska. Funded through state dollars, not local dollars.
- The success of service provider A and B is inspiring legislators to allocate funds to microtransit. Traditionally, these kind of funds have been more urban core focused but the policy-makers now start to see the value of these kind of services as a viable transit option outside of the norm.

Suburbs

- The service providers emphasizes strongly that whether microtransit works is dependent on the use case and environment. Suburb-to-suburb transit seems to be a good fit.
- Service provider A can now focus on serving suburban interests and needs, taking into consideration the land use, travel dynamics, demographics etc. which lend themselves for microtransit.
- 'Microtransit has the ability to make suburb to suburb transit a reality in a way that it never has been before.' But it also has other applications such as first mile last mile which is an application which is also served at the park 'n rides.

Traditional transit

- The traditional transit providers usually focuses more on urban or rural. Usually suburban is mixed in with the urban provider and generally is an afterthought for the urban provider.
- In the urban environment fixed routes might still make more sense. The first mile last mile is more confined to a certain space then in suburbs.
- The mix of microtransit and traditional transit should also be considered: a lightrail system (through southwestern suburbs to downtown Minneapolis) coming into the area in five years at a hotspot of the network in Eden Prairie.

Post-pandemic service provider A expects that they might see a shift from urban core focus to more suburb-to-suburb. Microtransit can create those kind of suburb-to-surburb connections. The core of the focus before covid was express service to downtown Minneapolis and the University of Minnesota.

B.2.3 Important Quotes

- 'You can live in the suburbs and have transit be a real part of your life, not a regular part of your life but just something that you know is an option for you.'
- 'Microtransit has the ability to make suburb to suburb transit a reality in a way that it never has been before.'
- 'What I like about microtransit is I can do anything I want with it.'
- 'I live in the suburbs I assume that there is no transit for me.'

- 'I wouldn't want to say we invented microtransit but we were close to it.'
- 'I was the one, you know I talk a lot about [our microtransit service] and give a lot of presentations on it and I would always say every other, especially when I talk to other transit systems they always are, they're like well this is working for you, it's awesome, we wanna do it. And I was like well it's not necessarily gonna work it depends on your use case at the end of the day. Each use case is unique.'

B.3 INTERVIEW B

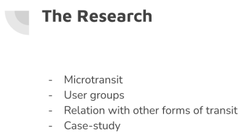
On April 13th, 20:30 Amsterdam Time, an online meeting/interview was conducted with several senior employees of transit agency B. During this meeting the interviewer (the author), the interviewees (the transit agency employees) and two third individuals (employees of the intermediary company coordinating the meeting) talked about the objectives, users and planning of the microtransit services. Below the prepared presentation and a transcript of the conversation can be found.

B.3.1 Prepared Presentation

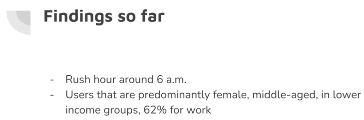
The presentation in Figure B.2 was presented to the interviewees before asking the prepared questions. The slides where the microtransit service name is mentioned are anonymised.

(a) Opening slide.

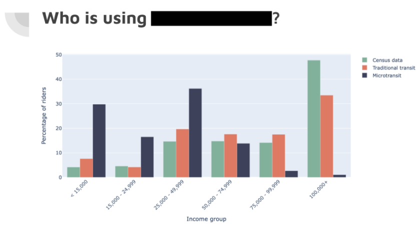
(b) Introduction to the interviewers background and the university.



(c) Introduction to the high-level themes of the research.

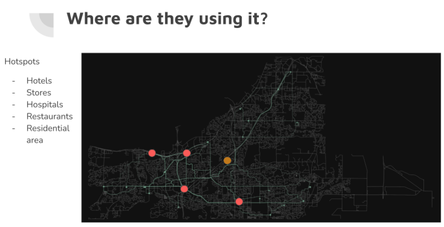


(d) Findings so far on temporal use and socio-economic indicators of users.

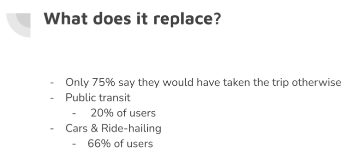


(e) Comparison of income level of microtransit riders, traditional transit riders and local population.

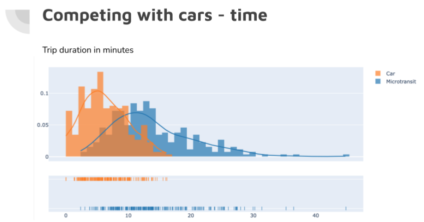
(f) Visualisation of the most popular hotspots in the service area.



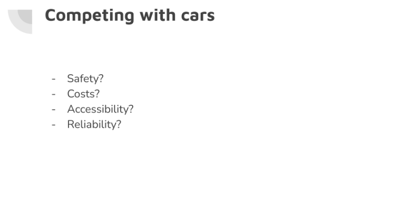
(g) Explanation of what is located at the hotspots.



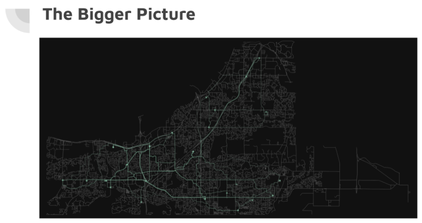
(h) Findings so far on what transit form users indicate they would otherwise use.



(i) Comparison of travel time with car and microtransit for the most popular routes.



(j) Introduction of a new survey question on why people choose microtransit.



(k) Reflection on the goals of the research and the upcoming findings.

(l) Questions slide.

Figure B.2: The slide deck for the presentation.

B.3.2 Summary

Users and transit-dependence

- The idea of super/power users is introduced by the provider. These users don't use microtransit on an occasional basis but use it almost daily for many of the same type of trips.
- There is no clear target audience but being in the suburbs of the Minneapolis-St.Paul region they know (stemming from traditional transit experience) that the local ridership is more of a transit-dependent population.
- The on-demand service has caused more choice-riders to move into the service because they enjoy using transit i.o. the car. The focus stays on transit-dependent population tho.

History

- The provider launched the microtransit service almost three years ago, have been with Spare for only one year.
- The provider wanted to take on the opportunity to expand the region and help with the first last mile problem.
- The service was launched in an area that had an existing local route that was a flex route where riders can call in and book a trip but that line was limited and low-performing.
- On-demand service was a way to expand and provide better service opportunities. Initially the service was focused around this fixed route area but it kept expanding because of the success with the goal of being a first mile last mile connector.
- The service doesn't seem to actually meet this first last mile connection completely, they are also serving many people that are not traditional transit users that now use microtransit for trips like commutes, which the provider doesn't see as a bad thing.

Traditional Transit

- The provider expects that in the future on-demand services will probably grow more, and the provider will have to work through balancing fixed route and on-demand in terms of amount and zones.
- On-demand is more oriented at first last mile and therefore the service provider looks for opportunities where there might be transit stations with a high frequency of connections and connect the microtransit to that.
- On-demand is also used as a way to justify cutting back on zones or routes when necessary, because on-demand is stilll available to the riders.

B.3.3 Important Quotes

- 'We still have the focus of being a first last mile connection but it's almost like it's an added benefit that we're reaching this new audience of customers.'

C DATA

C.1 CASE STUDY

This section details the characteristics of the selected case study area as well as an overview of the potential case study areas, demonstrating why some of them were eventually excluded from this study and why the two transit providers in the Minneapolis-St.Paul region were fit for this study.

C.1.1 Characteristics of the Case Study Area

A detailed comparison of the two service areas/providers is given in Table C.1. The cities included in the service area, population of these cities combined and level of car ownership is given. The total microtransit rides that have been recorded in the used data set and an estimate of the rides per month is also given. The operating times and fares are also provided.

Feature	Service provider A	Service Provider B
Cities	Eden Prairie, Chaska, Chanhassen, Carver and Victoria	Apple Valley, Burnsville, Eagan, Rosemount and Savage
Total population	136605	236103
Car ownership %	2.5% no vehicle, 27% no or 1 vehicle	3.3% no vehicle, 31% no or 1 vehicle
Total rides	195 662	66 762
Data available from	August 2019-April 2022	January 2021-April 2022
Rides per month	6 000	4 000
Operating times	Monday-Friday: 05:30-19:00, Saturday: 6:00-17:30	Every day 06:00-21:00
Fare	$4 for 6+, free when transferring from traditional public transit	$3 for 5+

Table C.1: Comparison of the service areas/providers A and B based on several service area and microtransit service characteristics.

C.1.2 Potential Case Study Areas

Section C.1.2 shows the potential case study areas and the data availability for them, supporting the eventual selection of the Minneapolis-St.Paul area as highlighted in Chapter 4.

Location		Microtransit data			Spatial socio-economic data		
Country	**City**	**Length of service**	**Size of service**	**Surveys conducted**	**Socio-economic indicators**	**Spatial level**	**Spatial distribution of jobs**
Canada	Durham, ON	1.5	Large	1	2021 Census	Dissemination area, 400-700 inhabitants	LEAP (paid service)
	Medicine Hat, AB	1.5	Small	2			
	Powell River, BC	1	Small	1			
Germany	Mannheim	1	Medium	-	Statistikatlas	500-700 inhabitants	-
Norway	Kongsberg	2.5	Small	1	Statistik Sentralbyrå	250 metres, 1-700 inhabitants	Geonorge
	Bodø	2	Small	-			
	Odda	2	Small	2			
Spain	Palma	2	Medium	3	Available but limited	Cities	-
U.S.A.	Vancouver, WA	0.5	Medium	-	2020 Census	Census block group, 600-3000 inhabitants	LEHD LODES
	Cheyenne, WY	1.5	Large	2			
	Lubbock, TX	2	Large	3			
	Dallas, TX	3	Large	-			
	Kansas City, MO	0.5	Small	-			
	Minneapolis-St Paul, MN	1	Large	1			
	Greater Attleboro, MS	0.5	Medium	1			
	Ashland, OR	2	Small	2			
	Nevada, NV	1.5	Medium	2			
	Eden Prairie, MN	2.5	Large	3			
	Mesquite, TX	2	Medium	1			
	Lincoln, NB	2	Large	1			
	Tucson, AZ	1	Large	1			

C.2 MICROTRANSIT DATA

This section gives an overview of data volume and details for the microtransit ridership and survey data, provided by Spare for the case study areas.

C.2.1 Ridership

Table C.2 shows the size of the ridership dataset before and after data cleaning.

		Number of rides
A	Before cleaning	195 662
	After cleaning	170 951
B	Before cleaning	66 762
	After cleaning	56 071
Total	Before cleaning	257 324
	After cleaning	227 022

Table C.2: Size of the ridership dataset

C.2.2 Survey

Table C.3 shows the number of data points available per survey round for both service providers. In total, 1479 respondents filled in the survey. After this table an overview is provided of the questions and potential answers were included in the survey.

Round	Period	Service provider A	Service provider B
1	October/November 2020	128	-
2	April/May/June 2021	582	60
3	November 2021	141	171
4	April 2022	218	179
	Total	1069	410

Table C.3: Responses available per survey round

Question: 'What was your main purpose for taking today's on-demand transit trip?'

- Work / Commute
- Unpaid care work
- School / University
- Shopping
- Leisure / Recreation
- Healthcare
- Visiting friends or family
- Connecting to long-distance travel
- Other

Question: If this on-demand transit service wasn't available for today's trip, would you have taken the trip using another form of transport?

- YES, I would have taken this trip on another form of transport
- NO, I would not have taken this trip at all

Question: If you answered YES to the previous question, what form of transport would you have otherwise used to make your trip?

- Private Car
- Carpool
- Bus
- Train

- Taxi / Ridehail (e.g. Uber/Lyft)
- Motorcycle
- Scooter
- Cycle
- Walk
- Other

Question: What is your age?

- Under 18 years old
- 18–24 years old
- 25–34 years old
- 35–44 years old
- 45–54 years old
- 55–64 years old
- 65–74 years old
- 75 years old or older
- Prefer not to say

Question: Please specify your gender

- Woman
- Man
- Transgender woman
- Transgender man
- Non-binary / Gender non-conforming
- Other
- Prefer not to say

Question: Please specify your ethnicity

- White
- Black / African American
- Hispanic (Latinx or Spanish origin)
- Native American / American Indian
- Asian or Pacific Islander
- Middle Eastern
- Other
- Prefer not to say

(only surveys 2-4) Question: Please specify your annual household income

- Less than $15,000

- $15,000–$24,999
- $25,000–$49,999
- $50,000–$74,999
- $75,000–$99,999
- $100,000 or more
- Prefer not to say

Question: Do you identify as a D/deaf, blind, or disabled person, or have a long-term health condition?

- Yes
- No
- Prefer not to say

(only survey 4) Question: If you answered the previous question: Why did you choose on-demand transit over this alternative mode of transport? [Choose 1 or more]

- Cheaper
- Safer
- More convenient
- More reliable
- Better suited to my needs
- Other

C.3 TRADITIONAL TRANSIT DATA

This section gives an overview of the survey and routing data of the traditional transit network in the area.

C.3.1 Survey

The traditional transit on-board survey with 30606 responses was extracted from Metropolitan Council [2017]. It was filtered based on whether an origin or destination was in the service area and therefore (part of) the trip could have been taken with microtransit. This resulted in 1774 survey responses remaining.

C.3.2 GTFS

Due to computational limitations not all individual transit schedules could be used. Instead one schedule was used per year. The schedules that were extracted from Interland Technologies [2022] and used in the analysis are shown in Table C.4. MVTA records were downloaded from Transitland [2022a] and for a combined dataset of Plymouth, University of Minnesota, Other, Metro Transit, SouthWest Transit, Metro Transit, Airport (MAC), Maple Grove, Metro Transit/Met Council [Transitland, 2022b]. The last row shows the data that was used for the accessibility analyses which area described in Section 5.4 while the other rows show the data used for comparison of trips in Section 5.3.

Area	Year	Schedule used
A	2019	Aggregated metro transit 2019-09-21 up until 2019-12-06, MVTA 2019-09-03 up until 2019-11-15
	2020	Aggregated metro transit 2020-09-12 up until 2020-10-30, MVTA 2020-09-01 up until 2020-11-20
	2021	Aggregated metro transit 2021-08-28 up until 2021-10-15, MVTA 2021-09-15 up until 2021-11-19
	2022	Aggregated metro transit 2022-04-30 up until 2022-06-17, MVTA 2022-03-04 up until 2022-05-20
B	2021	MVTA 2021-09-15 up until 2021-11-19
	2022	2022-03-04 up until 2022-05-20
Full (accessibility analysis)	2022	Aggregated metro transit 2022-05-14 up until 2022-07-01, MVTA 2022-05-14 up until 2022-08-19

Table C.4: GTFS files used for the trip planning efforts per service provider and year.

C.4 SOCIO-ECONOMIC DATA

A combination of place-level and block (group) level data was extracted from the Census Bureau to shed light on socio-economic characteristics of the residents of the service areas. Place level was extracted for the 10 cities that cover the service area, block (group) level contains the corresponding block (groups) for the 2020 or 2010 census (in the case of LEHD-LODES data, which was most recently available for 2019 and therefore had to be matched to 2010 census blocks and population centers). Data is extracted from United States Census Bureau [2022] as well as US Census Bureau [2022b] and US Census Bureau [2022a].

C.5 LAND-USE

The data from Metropolitan Council [2021] was aggregated to higher level land-use categories, as shown in Table C.5. For the figures Figure 5.4 and Figure 5.5 the data set for the entire metropolitan area was filtered on the data overlapped with the 2020 municipal boundaries of the studied cities.

Aggregated category	Original categories
Residential	Multifamily, Single Family Detached, Single Family Attached, Mixed Use Residential, Manufactured Housing Park
Retail and Commercial	Retail and Commercial, Mixed Use Commercial
Park, Recreational, or Preserve	Park, Recreational, or Preserve, Golf Course
Agricultural	Agricultural, Farmstead
Industrial or Utility	Industrial or Utility, Mixed Use Industrial
Transport	Major Highway, Major Railway, Airport or Airstrip
Institutional	Institutional
Office	Office
Other	Undeveloped, Open Water, Extractive, Seasonal/Vacation

Table C.5: Aggregated and original land-use categories

Characteristic	Code and name	Year	Geo-level
Age	S0101 age and sex	2020: ACS 5-Year Estimates	Place
Gender	S0101 age and sex	2020: ACS 5-Year Estimates	Place
Ethnicity	P1 race	2020: DEC Redistricting Data (PL 94-171)	Place
Income	S1901: income in the past 12 months (in 2020 inflation-adjusted dollars)	2020: ACS 5-Year Estimates Subject Tables (2019 for Carver)	Place
Disability	S1810 disability characteristics	2020: ACS 5-Year Estimates Subject Table	Place
Commute mode	B08301: means of transportation to work	2020: ACS 5-Year Estimate	Place
Income	B19013: median household income in the past 12 months (in 2020 inflation-adjusted dollars)	2020: ACS 5-Year Estimate	Block group
Employment	B23025: Employment status for the population 16 years and over	2020: ACS 5-Year Estimate	Block group
Car ownership	B25044: tenure by vehicles available	2020: ACS 5-Year Estimate	Block group
Population	B01001: sex by age	2020: ACS 5-Year Estimate	Block group
Spatial	TIGER/Line	2020	Place
Spatial	TIGER/Line	2020	Block groups
Spatial	TIGER/Line	2019	Block groups
Population centers		2019	Block group
Population centers		2020	Block group

Table C.6: Code, geographic levels and years for the census data used in this thesis.

C.6 INFRASTRUCTURE AND AMENITIES DATA

To retrieve data on the infrastructure of the studied areas extracts were made using BBBike [Schneider, 2022]. The following coordinate areas were extracted:

- Service area A: coordinates: [["-93.711","44.821"], ["-93.666","44.733"], ["-93.606","44.734"], ["-93.503","44.761"], ["-93.388","44.773"], ["-93.227","44.835"], ["-93.17","44.897"], ["-93.385","44.896"], ["-93.713","44.896"], ["-93.729","44.849"]]
- Service area B: coordinates: [["-93.302","44.829"], ["-93.424","44.798"], ["-93.428","44.716"], ["-93.214","44.684"], ["-93.012","44.702"], ["-93.022","44.799"], ["-93.075","44.875"], ["-93.212","44.873"], ["-93.262","44.866"]]
- Full metropolitan area: coordinates: [["-93.917","44.552"], ["-93.267","44.549"], ["-93.249","44.481"], ["-92.597","44.599"], ["-92.798","44.757"], ["-92.764","44.911"], ["-92.752","45.144"], ["-92.795","45.291"], ["-93.521","45.295"], ["-93.526","45.238"], ["-93.792","45.137"], ["-93.813","45.031"], ["-93.977","45.019"]]

Overpass Turbo [Nominatim, 2022] was used as a tool to extract OSM data for the area. The keywords used to find the data are shown in Table C.7

C.6.1 Jobs

The Workspace Area Characteristics were extracted from Census Bureau [2019]. Version LODES 7 was used for the state Minnesota and the type Workplace Area Characteristics, the most recent version of this data was from 2019. The data was filtered

Point of interest	Search terms
Shops	key=shop
Healthcare points	amenity=clinic, amenity=doctors, amenity=hospital

Table C.7: Points of interest and keys used to identify them with the Overpass Turbo API.

on the 7-county metropolitan area. The data was then aggregated to block group level and matched to the population centers for those block groups.

D STATISTICS

In this appendix tables and results for statistical tests that were conducted to prove significance of the results is given. The chi-squared test was regularly used for this purpose.

D.1 INCOME

Income level of microtransit survey respondents vs. overall population

- Census household population: 139 981
- Microtransit population: 1479, 920 answered this question.
- Degrees of freedom: 5
- Critical value for $\alpha = 0.05$: 11.070
- Critical value for $\alpha = 0.01$: 15.086

$3044.19 > 15.09$, therefore we have shown that the income level of the microtransit riders for this survey subset is not distributed in accordance with the distribution of the income level in this area overall.

	Census	Microtransit		Chi-squared	
Income groups	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
<$15,000	4.12%	222	24.13%	37.91	893.94
$15,000 - $24,999	4.04%	289	31.41%	37.12	1,708.92
$25,000 - $49,999	14.01%	209	22.72%	128.85	49.86
$50,000 - $74,999	15.15%	78	8.48%	139.38	27.03
$75,000 - $99,999	13.41%	50	5.43%	123.36	43.63
$100,000+	49.28%	72	7.83%	453.38	320.81
Total		920			3,044.19
Not filled in		559	37.80%		

Table D.1: Relative distribution of respondents across income groups for microtransit survey respondents and census data and results of the chi-squared test for statistical significance of the difference between those two groups.

Income level of microtransit vs. traditional transit survey respondents

- TBI population 1774, 1635 filled in this question.
- Microtransit population: 1479, 920 answered this question.
- Degrees of freedom: 1
- Critical value for $\alpha = 0.05$: 6.31
- Critical value for $\alpha = 0.01$: 31.82

$1267.06 > 31.82$, therefore we have shown that the income of the microtransit riders for this survey subset is not distributed in accordance with the distribution of income in the public transit riders in this area overall.

	TBI		Microtransit		Chi-squared	
Income groups	**Absolute**	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
<$24,999	235	14.37%	511	55.54%	132	1084.94
>$25,000	1400	85.63%	409	44.46%	788	182.12
Total	1635	100.00%	920	100.00%		1267.06
Not fillled in	139		559	37.80%		

Table D.2: Relative distribution of respondents across lower and higher income group for microtransit and traditional transit survey respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

Income level of survey respondents vs. reason for choosing microtransit

- Microtransit population: 360 for this round
- Degrees of freedom: 5
- Critical value for $\alpha = 0.05$: 11.070
- Critical value for $\alpha = 0.01$: 15.086

$2.94 < 15.086$, therefore we cannot reject the hypothesis that reasons for choosing microtransit over alternative transit options is equally distributed amongst income level groups of the microtransit riders for this survey subset.

	<24,999		Overall		Chi-squared	
	Absolute	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
Why on-demand?						
Cheaper	59	59.60%	212	58.89%	58.30	0.01
More convenient	43	43.43%	185	51.39%	50.88	1.22
Safer	36	36.36%	106	29.44%	29.15	1.61
More reliable	30	30,30%	105	29,17%	28.88	0,04
Better suited to my needs	33	33.33%	121	33.61%	33.28	0.00
Other	11	11.11%	43	11.94%	11.83	0.06
Total	99		360			2.94
Not filled in	19					

Table D.3: Distribution of reasons for choosing microtransit over alternative modes of transit for the respondents with an annual household income below 24 999 dollars and all respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

D.1.1 Scatterplots

For these scatterplots the trip origins before 11 and trip destinations after 16 were used. This was done to create a better estimate of the home location of the riders. The data was then aggregated to block group level to create counts of trips per block group.

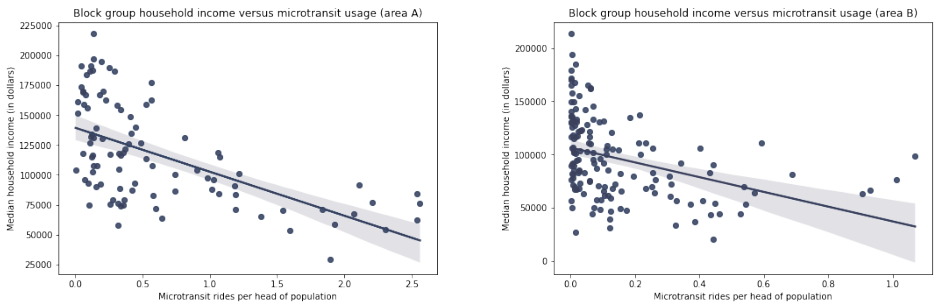
A: income vs. microtransit trips

- R-squared: 0.337
- Adjusted R-squared: 0.330
- F-statistic: 48.27

- Prob (F-statistic): 4.62e-10
- Log-Likelihood: -1149.8
- AIC: 2304.
- BIC: 2309.

B: income vs. microtransit trips
OLS regression results

- R-squared: 0.097
- Adjusted R-squared: 0.091
- F-statistic: 15.96
- Prob (F-statistic): 0.000101
- Log-Likelihood: 32.935
- AIC: -61.87
- BIC: -55.84



(a) (b)

Figure D.1: Trips per head of population plotted against median household income with an OLS trendline, for both service areas.

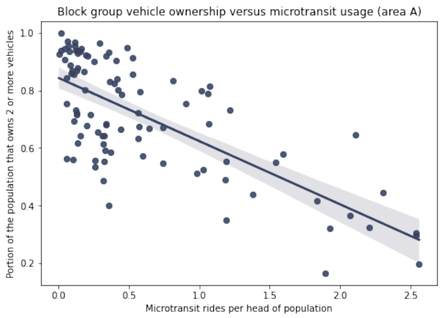
A: car ownership vs. microtransit trips OLS regression results

- R-squared: 0.525
- Adjusted R-squared: 0.519
- F-statistic: 104.8
- Prob (F-statistic): 5.16e-17
- Log-Likelihood: 54.680
- AIC: -105.4
- BIC: -100.2

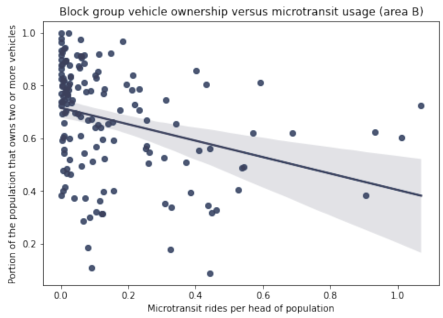
B: car ownership vs. microtransit trips filtered out one point that had more than 2 trips per head of population

- R-squared: 0.142
- Adjusted R-squared: 0.136
- F-statistic: 24.57

- Prob (F-statistic): 1.93e-06
- Log-Likelihood: -1793.7
- AIC: 3591.
- BIC: 3598.



(a)



(b)

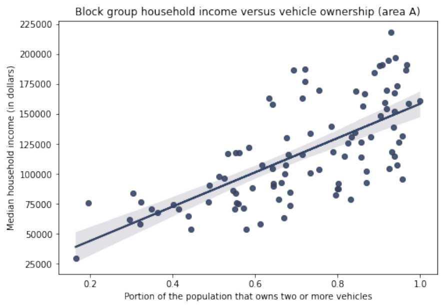
Figure D.2: Trips per head of population plotted against portion of the population that owns 2 or more vehicles with an OLS trendline, for both service areas.

A: car ownership vs. income OLS regression results

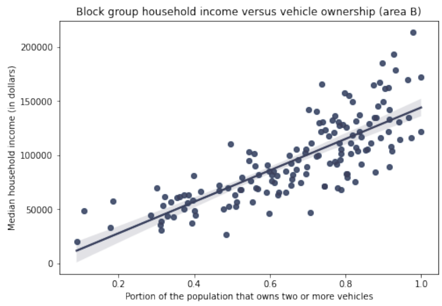
- R-squared: 0.468
- Adjusted R-squared: 0.462
- F-statistic: 83.59
- Prob (F-statistic): 1.12e-14
- Log-Likelihood: -1139.1
- AIC: 2282.
- BIC: 2287.

B: car ownership vs. income OLS regression results

- R-squared: 0.626
- Adjusted R-squared: 0.623
- F-statistic: 250.6
- Prob (F-statistic): 8.22e-34
- Log-Likelihood: -1743.3
- AIC: 3491.
- BIC: 3497.



(a)



(b)

Figure D.3: Median household income plotted against portion of the population that owns 2 or more vehicles with an OLS trendline, for both service areas.

D.2 AGE

- Census population: 238 191
- Transit On-board Survey population: 1774
- Microtransit population: 1479, 1447 answered this question. When excluding population under 18 years: 1385
- Degrees of freedom: 7
- Critical value for $\alpha = 0.05$: 14.07
- Critical value for $\alpha = 0.01$: 18.48

Age group for microtransit survey respondents vs. overall population
$460.26 > 18.48$, therefore we have shown that the age of the microtransit riders for this survey subset is not distributed in accordance with the distribution of age in this area overall.

	Census	Microtransit		Chi-squared	
Age groups	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
Under 18 years	24.72%	62	4.28%	357.69	244.44
18 to 24 years	7.57%	119	8.22%	109.48	0.83
25 to 34 years	12.73%	176	12.16%	184.15	0.36
35 to 44 years	14.01%	349	24.12%	202.67	105.65
45 to 54 years	13.80%	243	16.79%	199.71	9.38
55 to 64 years	13.81%	336	23.22%	199.78	92.88
65 to 74 years	8.47%	111	7.67%	122.49	1.08
75 years and over	4.91%	51	3.52%	71.02	5.64
Total		1447			460.26
Not filled in		32			

Table D.4: Relative distribution of respondents across age groups for microtransit survey respondents and census data and results of the chi-squared test for statistical significance of the difference between those two groups.

Excluding under 18: we also ran the test excluding the riders under 18 since the most significant difference in distribution came from this factor. This gave different degrees of freedom as well as critical values.

- Degrees of freedom: 6
- Critical value for $\alpha = 0.05$: 12.59
- Critical value for $\alpha = 0.01$: 16.81

104.7 > 16.81, therefore we have shown that the age of the microtransit riders for this survey subset is not distributed in accordance with the distribution of age in this area overall, even when excluding the population under 18.

	Census	Microtransit		Chi-squared	
Age groups	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
18 to 24 years	10.05%	119	8.59%	145.43	4.80
25 to 34 years	16.91%	176	12.71%	244.62	19.25
35 to 44 years	18.61%	349	25.20%	269.22	23.64
45 to 54 years	18.33%	243	17.55%	265.29	1.87
55 to 64 years	18.34%	336	24.26%	265.38	18.79
65 to 74 years	11.25%	111	8.01%	162.72	16.44
75 years and over	6.52%	51	3.68%	94.34	19.91
Total		1385			104.70
Not filled in / under 18		94			

Table D.5: Relative distribution of respondents across age groups, excluding the age group under 18, for microtransit survey respondents and census data and results of the chi-squared test for statistical significance of the difference between those two groups.

Age group of microtransit vs. traditional transit survey respondents

715.19 > 18.48, therefore we have shown that the age of the microtransit riders for this survey subset is not distributed in accordance with the distribution of age for traditional transit.

	TBI	Microtransit		Chi-squared	
Age groups	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
Under 18 years	2.20%	62	4.28%	31.81	28.65
18 to 24 years	17.08%	119	8.22%	247.15	66.45
25 to 34 years	25.42%	176	12.16%	367.87	100.07
35 to 44 years	19.95%	349	24.12%	288.75	12.57
45 to 54 years	18.49%	243	16.79%	267.54	2.25
55 to 64 years	13.25%	336	23.22%	191.68	108.66
65 to 74 years	3.16%	111	7.67%	45.68	93.42
75 years and over	0.45%	51	3.52%	6.53	303.12
Total		1447			715.19
Not filled in		32			

Table D.6: Relative distribution of respondents across age groups for microtransit and traditional transit survey respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

Age group of survey respondents vs. reason for choosing microtransit

- Microtransit population: 360 for this round
- Degrees of freedom: 5
- Critical value for $\alpha = 0.05$: 11.070
- Critical value for $\alpha = 0.01$: 15.086

12.83 > 11.070 but 12.83 < 15.086, therefore we cannot reject the hypothesis that reasons for choosing microtransit over alternative transit options is equally distributed amongst the 35-64 age group of microtransit riders and all microtransit riders for this survey subset with more than 0.05 confidence.

2.29 < 11.070, therefore we cannot reject the hypothesis that reasons for choosing microtransit over alternative transit options is equally distributed amongst the 35-64 age group of microtransit riders and all microtransit riders for this survey subset.

8.89 < 11.070, therefore we cannot reject the hypothesis that reasons for choosing microtransit over alternative transit options is equally distributed amongst the 65+ age group of microtransit riders and all microtransit riders for this survey subset.

	<34		Overall		Chi-squared	
	Absolute	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
Why on-demand?						
Cheaper	56	71.79%	212	58.89%	45.93	2.21
More convenient	40	51.28%	185	51.39%	40.08	0
Safer	33	42.31%	106	29.44%	22.97	4.38
More reliable	31	39.74%	105	29.17%	22.75	2.99
Better suited to my needs	35	44.87%	121	33.61%	26.22	2.94
Other	11	14.10%	43	11.94%	9.32	0.30
Total	78		360			12.83
Not filled in	17					

Table D.7: Distribution of reasons for choosing microtransit over alternative modes of transit for the respondents in the age category 34 and under and all respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

	34-64		Overall		Chi-squared	
	Absolute	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
Why on-demand?						
Cheaper	125	55.07%	212	58.89%	133.68	0.56
More convenient	109	48.02%	185	51.39%	116.65	0.50
Safer	60	26.43%	106	29.44%	66.84	0.70
More reliable	31	39.74%	105	29,17%	66.21	0,02
Better suited to my needs	35	44.87%	121	33.61%	76.30	0.14
Other	24	10.57%	43	11.94%	27.11	0.36
Total	227		360			2.29
Not filled in	5					

Table D.8: Distribution of reasons for choosing microtransit over alternative modes of transit for the respondents in the age category between 35 and 64 and all respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

Why on-demand?	65+ Absolute	Relative	Overall Absolute	Relative	Chi-squared Expected	Value
Cheaper	27	55.10%	212	58.89%	28.86	0.12
More convenient	30	61.22%	185	51.39%	25.18	0.92
Safer	10	20.41%	106	29.44%	14.43	1.36
More reliable	7	14.29%	105	29.17%	14.29	3.72
Better suited to my needs	10	20.41%	121	33.61%	16.47	2.54
Other	7	14.29%	43	11.94%	5.85	0.22
Total	49		360			8.89
Not filled in	15					

Table D.9: Distribution of reasons for choosing microtransit over alternative modes of transit for the respondents in the age category 65 and up and all respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

D.3 GENDER

- Census population: 370 615
- Microtransit population: 1479, 1449 filled in this question.
- Degrees of freedom: 1
- Critical value for $\alpha = 0.05$: 3.84
- Critical value for $\alpha = 0.01$: 6.63

$0.48 < 3.84$, therefore we cannot reject the hypothesis that gender is equally distributed amongs microtransit riders as it is amongst the general population of the area.

Gender	Census Relative	Microtransit Absolute	Relative	Chi-squared Expected	Value
Male	48.99%	705	48.65%	709.90	0.03
Female	51.01%	721	49.76%	739.10	0.44
Non-binary, non-conforming or other		23	1.59%		
Total		1449			0.48
Not filled in		30			

Table D.10: Relative distribution of respondents across genders for microtransit survey respondents and census data and results of the chi-squared test for statistical significance of the difference between those two groups.

D.4 DISABILITY

- Census population: 369 547
- Transit On-board Survey population: 1774
- Microtransit population: 1479, 1221 filled in this question.
- Degrees of freedom: 1

- Critical value for $\alpha = 0.05$: 3.84
- Critical value for $\alpha = 0.01$: 6.63

Disability status of microtransit survey respondents vs. overall population
1095.60 > 3.84, therefore we have shown that the disability status of the microtransit riders for this survey subset is not distributed in accordance with the distribution of disability status in this area overall.

	Census	Microtransit		Chi-squared	
Disability Status	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
Disabeled	7.75%	404	33.09%	94.67	1,010.65
Non-disabled	92.25%	817	66.91%	1,126.33	84.95
Total		1221			1,095.60
Not filled in		258	17.44%		

Table D.11: Relative distribution of respondents across disability status for microtransit survey respondents and census data and results of the chi-squared test for statistical significance of the difference between those two groups.

Disability status of microtransit vs. traditional transit survey respondents
1703.85 > 3.84, therefore we have shown that the disability status of the microtransit riders for this survey subset is not distributed in accordance with the distribution of disability status in the traditional transit network in this area overall.

	TBI	Microtransit		Chi-squared	
Disability Status	**Relative**	**Absolute**	**Relative**	**Expected**	**Value**
Disabeled	5.69%	404	33.09%	69.52	1,609.41
Non-disabled	93.86%	817	66.91%	1,145.98	94.44
Total		1221			1,703.85
Not filled in	0.45%	258	17.44%		

Table D.12: Relative distribution of respondents across disability status for microtransit and traditional transit survey respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

D.5 RACE

- Census population: 381 991
- Transit On-board Survey population: 1774, 1763 answered this question
- Microtransit population: 1479, 1399 filled in this question.
- Degrees of freedom: 5
- Critical value for $\alpha = 0.05$: 11.07
- Critical value for $\alpha = 0.01$: 15.09

Race of microtransit survey respondents vs. overall population
214.05 > 15.09, therefore we have shown that the ethnicity of the microtransit riders for this survey subset is not distributed in accordance with the distribution of ethnicity in the overall population of this area.

Race of microtransit vs. traditional transit survey respondents
68.29 > 15.09, therefore we have shown that the ethnicity of the microtransit riders for this survey subset is not distributed in accordance with the distribution of ethnicity in the traditional transit riders in this area.

Ethnicity	Census Relative	Microtransit Absolute	Microtransit Relative	Chi-squared Expected	Chi-squared Value
White	72.85%	864	61.76%	1,019.16	23.62
Black	8.37%	232	16.58%	117.13	112.64
Native American / American Indian	0.43%	26	1.86%	5.97	67.27
Asian or pacific islander	8.07%	98	7.01%	112.85	1.95
Other (hispanic, more than one race)	10.29%	179	12.79%	143.90	8.56
Total		1399			214.05
Not fillled in		80			

Table D.13: Relative distribution of respondents across race identities for microtransit survey respondents and census data and results of the chi-squared test for statistical significance of the difference between those two groups.

Ethnicity	Census Relative	Microtransit Absolute	Microtransit Relative	Chi-squared Expected	Chi-squared Value
White	67.56%	864	61.76%	945.10	6.96
Black	14.46%	232	16.58%	202.35	4.34
Native American / American Indian	1.08%	26	1.86%	15.08	7.91
Asian or pacific islander	9.02%	98	7.01%	126.17	6.29
Other (hispanic, more than one race)	7.88%	179	12.79%	110.30	42.79
Total		1399			68.29
Not fillled in		80			

Table D.14: Relative distribution of respondents across race identities for microtransit and traditional transit survey respondents and results of the chi-squared test for statistical significance of the difference between those two groups.

D.6 LAND-USE

This section gives an overview of the tabulated data that underlies the statements and figures shown in Section 5.2.

Land use	Relative
Residential	82.71%
Retail and Commercial	62.16%
Transport	14.54%
Industrial or Utility	11.81%
Institutional	11.49%
Park, Recreational, or Preserve	6.88%
Office	6.28%
Other	4.14%

Table D.15: Distribution of trip origins and destinations across different aggregated land-use categories.

Landuse Pickup	Landuse Dropoff	Relative
Residential	Retail and Commercial	40.70%
Residential	Transport	8.90%
Residential	Institutional	7.23%
Residential	Industrial or Utility	6.39%
Residential	Residential	5.87%
Retail and Commercial	Retail and Commercial	5.66%

Table D.16: Distribution of specific combinations of land-use for trip origins and destinations across aggregated land-use categories.

D.7 FIXED AND VARIABLE VEHICLE COSTS

The calculation of cost per kilometer driven are based on the following information:

- The average gas price is about 4.25 per gallon AAA Gas Prices [2022].
- One gallon is 3.785 liter.
- An average car uses around 9.4 liters of gas per 100 kilometers IEA [2020]. Therefore, 1 kilometer uses 0.094 liters of gas.

The formula below shows how the price per kilometer was calculated. In this formula, P stands for price per kilometer.

$$P = \frac{4.25}{3.785} * 0.094 = 0.105 \tag{D.1}$$

To calculate the average annual vehicles costs provided by [AAA, 2019] was used and the costs of driving 15 000 miles were subtracted from this average.

D.8 TRAVEL PURPOSES

Table D.17 shows the distribution of indicated travel purpose across the microtransit survey respondents.

Travel Purpose	Percentage of survey responses
Work/commute	56.46%
Shopping	13.79%
Leisure/Recreation	8.59%
Healthcare	6.49%
School/University	4.33%
Other	4.06%
Connecting to long-distance travel	3.52%
Visiting friends or family	2.77%

Table D.17: Relative number of indicated travel purpose for all microtransit survey respondents.

D.9 REPLACEMENT MODES

Table D.18 shows the distribution of indicated replacement mode across the microtransit survey respondents, both for seperate and combined service providers.

Replacement mode	A	B	Total
Taxi / Ridehail	62.22%	48.25%	58.12%
Bus or train	3.04%	18.73%	7.65%
Private car	19.29%	15.87%	18.28%
Walk	5.42%	7.30%	5.97%
Carpool	2.91%	1.59%	2.52%
Other	7.13%	8.25%	7.46%

Table D.18: Relative number of indicated replacement mode for all microtransit survey respondents for the service areas seperately and combined.

D.10 TIME GAINS AND LOSSES WITH REPLACEMENT MODES

This sections shows the tables that support the figures in Section 5.3 on travel time gains with different transport modes.

D.10.1 Cars

Table D.19 shows the travel time comparison of all studied microtransit trips with personal car use, both including and excluding wait and walking time. A total of 227022 trips were planned in OTP, 208394 (91.06%) of these trips resulted in a personal car alternative

		% Trips where car was faster	% Trips where car was 10+ minutes faster	% Trips where car was 30+ minutes faster	Average seconds car is faster	Average times car is faster
A	**Including wait time**	95.34%	68.25%	19.16%	1158	2.74
	Excluding wait time	54.48%	12.49%	0.60%	178	1.32
B	**Including Wait time**	94.70%	35.27%	5.93%	665	2.15
	Excluding wait time	44.21%	6.12%	0.12%	31	1.17
Total	**Including wait time**	95.18%	59.91%	15.81%	1032	2.59
	Excluding wait time	51.88%	10.88%	0.48%	140	1.282

Table D.19: Difference in travel time between (personal) car and microtransit.

D.10.2 Public Transit

Table D.20 shows the travel time comparison of all studied microtransit trips with personal car use, both including and excluding wait and walking time. A total of 227022 trips were planned in OTP, 219893 (96.86%) of these trips resulted in a public transit alternative run, but only 71010 (23,29%) of these actually involved boarding a public transit vehicle.

D.10.3 Walking

Table D.21 shows the travel time comparison of all studied microtransit trips with walking alternatives, both including and excluding wait and walking time. A total

		% Trips with no public transit alternative	% Trips where microtransit was faster	% Microtransit was 10+ min faster	% Microtransit was 30+ min faster	Average seconds microtransit is faster	Average times microtransit is faster
A	Including wait time	75.06%	88.11%	83.86%	69.79%	3549	2.70
	Excluding wait time	-	99.67%	98.19%	92.25%	4953	6.67
B	Including Wait time	44.62%	80.67%	61.17%	53.82%	1181	1.87
	Excluding wait time	-	97.48%	85.40%	54.97%	1936	3.88
Total	Including wait time	67.71%	85.03%	74.46%	63.17%	2568	2.35
	Excluding wait time	-	98.76%	92.89%	76.80%	3703	5.51

Table D.20: Difference in travel time between public transit and microtransit.

of 22702 trips were planned in OTP, 224911 (99.07%) of these trips resulted in a walking alternative.

	% Trips where microtransit was faster	% Microtransit was 10+ min faster	% Microtransit was 30+ min faster	% Microtransit was 1+ hour faster	Average seconds microtransit is faster	Average times microtransit is faster	Average walking distance
Excluding wait time	99.37%	95.54%	73.64%	54.78%	4488	7.55	6926
Including wait time	88.32%	78.33%	56.54%	33.01%	3353	2.98	-

Table D.21: Difference in travel time for walking and microtransit.

D.11 CUMULATIVE ACCESS

D.11.1 Cumulative Access to Jobs

Table D.22 shows the average number of jobs that can be reached with different transit modes from the two service areas seperately and combined.

D.11.2 Cumulative Access to Shops

Table D.23 shows the average number of shops that can be reached with different transit modes from the two service areas seperately and combined.

D.11.3 Cumulative Access to Healthcare Facilities

Table D.24 shows the average number of healthcare facilities that can be reached with different transit modes from the two service areas seperately and combined.

		Car	Transit	Microtransit	Microtransit and other transit	% Increase in jobs reached by addition of microtransit
A	**Under 30 minutes**	399175	3371	89772	89843	2565.16%
	Under 1 hour	1546958	21854	99902	108179	395.01%
B	**Under 30 minutes**	419538	8589	75770	77224	799.16%
	Under 1 hour	1587417	103649	98356	167127	61.24%
Total	**Under 30 minutes**	412075	6676	80902	81849	1125.98%
	Under 1 hour	1572588	73669	98922	145522	97.53%

Table D.22: Difference in average amount of jobs reached within 30 minutes or 1 hour, separated per service area as well as combined.

		Car	Transit	Microtransit	Microtransit and other transit	% Increase in healthcare points reached by addition of microtransit
A	**Under 30 minutes**	726	3	61	61	2229.66%
	Under 1 hour	2824	18	71	65	296.61%
B	**Under 30 minutes**	934	46	190	207	353.72%
	Under 1 hour	2850	138	230	306	121.18%
Total	**Under 30 minutes**	860	30	144	155	411.16%
	Under 1 hour	1841	96	171	223	133.07%

Table D.23: Difference in average amount of shops reached within 30 minutes or 1 hour, separated per service area as well as combined.

		Car	Transit	Microtransit	Microtransit and other transit	% Increase in healthcare points reached by addition of microtransit
A	**Under 30 minutes**	17	0	3	4	-
	Under 1 hour	97	1	4	4	585.48%
B	**Under 30 minutes**	24	0	6	6	-
	Under 1 hour	98	5	8	11	124.85%
Total	**Under 30 minutes**	22	0	5	5	-
	Under 1 hour	68	3	6	8	167.83%

Table D.24: Difference in average amount of healthcare facilities reached within 30 minutes or 1 hour, separated per service area as well as combined.

E LORENZ CURVES & GINI COEFFICIENTS

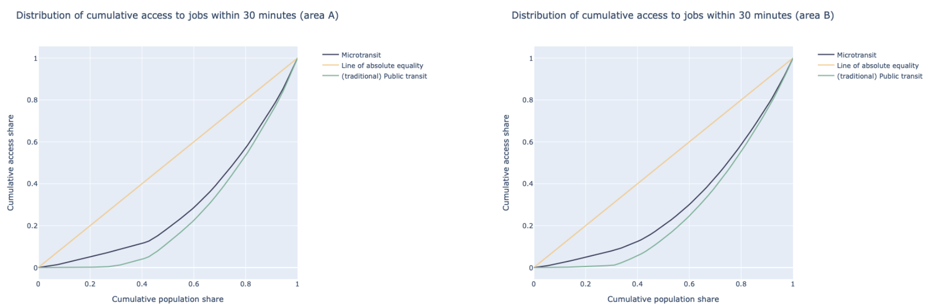
In this section all Lorenz curves, gini coefficients and significance indicators are given. For each service type category these are given for both areas and with 30 minutes and 1 hour, all with scenario 1 in mind. For the aggregated access the scores and figures are given for each scenario (1-3) and for both service areas. To show significance of results a two-sample Kolmogorov-Smirnov test for goodness of fit was conducted for all distributions. A maximum p-value of 0.01 is used for significance testing.

E.1 JOBS

Table E.1 shows that for both areas jobs reachable within 30 minutes has a highly significant p-value and jobs reachable within 1 hour has a higher, but for service area A still significant, p-value.

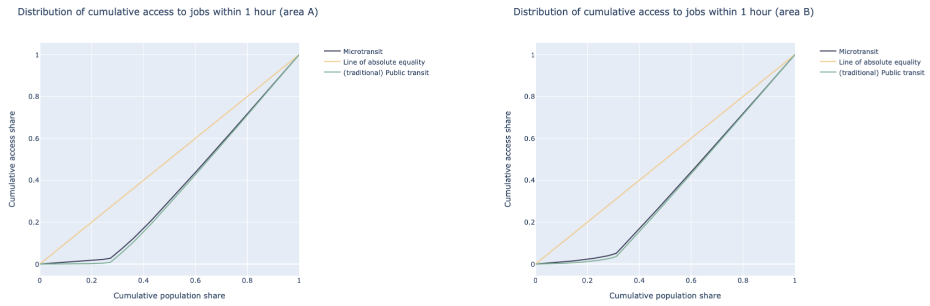
Area	Category	Gini without microtransit	Gini with microtransit	P-value	D-statistic
A	Jobs within 30 minutes	0.498	0.407	1.628780016 1573211e-07	0.492307692 30769234
	Jobs within 1 hour	0.294	0.274	0.000246358 92376346905	0.369230769 23076925
B	Jobs within 30 minutes	0.475	0.392	4.578992967 1962165e-07	0.349593495 93495936
	Jobs within 1 hour	0.289	0.272	0.106279309 2124499	0.154471544 71544716

Table E.1: Gini coefficients before and after microtransit intervention and p-value and d-statisic to test significance of difference between the distributions for cumulative access to jobs.



(a) Area A. **(b)** Area B.

Figure E.1: The Lorenz curves showing the distribution of cumulative access to jobs within 30 minutes.



(a) Area A. **(b)** Area B.

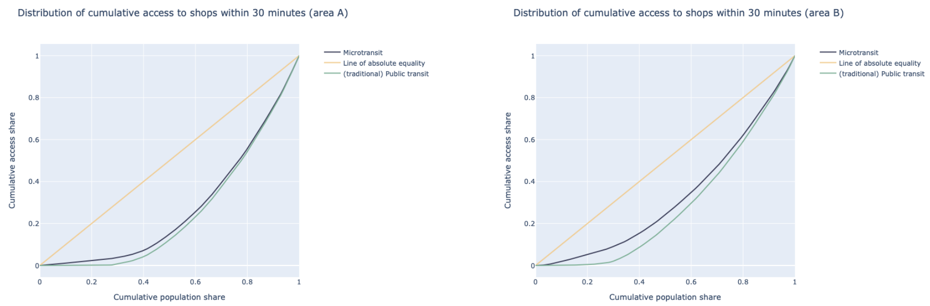
Figure E.2: The Lorenz curves showing the distribution of cumulative access to jobs within one hour.

E.2 SHOPS

Table E.2 shows that for both areas shops reachable within 30 minutes has a highly significant p-value and jobs reachable within 1 hour has a higher, but for both service areas still significant, p-value.

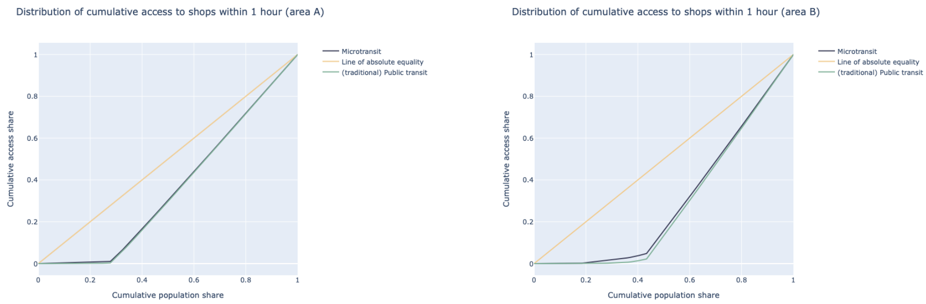
Area	Category	Gini without microtransit	Gini with microtransit	P-value	D-statistic
A	Shops within 30 minutes	0.491	0.453	5.627221518096178e-06	0.4444444444444444
	Shops within 1 hour	0.288	0.281	0.0008342035229139418	0.3492063492063492
B	Shops within 30 minutes	0.426	0.346	1.5228713099092461e-05	0.3064516129032258
	Shops within 1 hour	0.424	0.402	0.0034888081470730707	0.22580645161290322

Table E.2: Gini coefficients before and after microtransit intervention and p-value and d-statisic to test significance of difference between the distributions for cumulative access to shops.



(a) Area A. **(b)** Area B.

Figure E.3: The Lorenz curves showing the distribution of cumulative access to shops within one hour.



(a) Area A. (b) Area B.

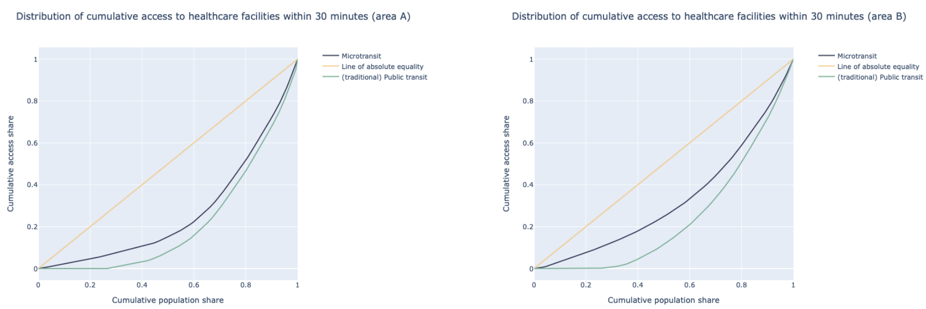
Figure E.4: The Lorenz curves showing the distribution of cumulative access to shops within one hour.

E.3 HEALTHCARE FACILITIES

Table E.3 shows that for both areas healthcare facilities reachable within 30 minutes has a highly significant p-value and jobs reachable within 1 hour has a higher, but for service area A still significant, p-value.

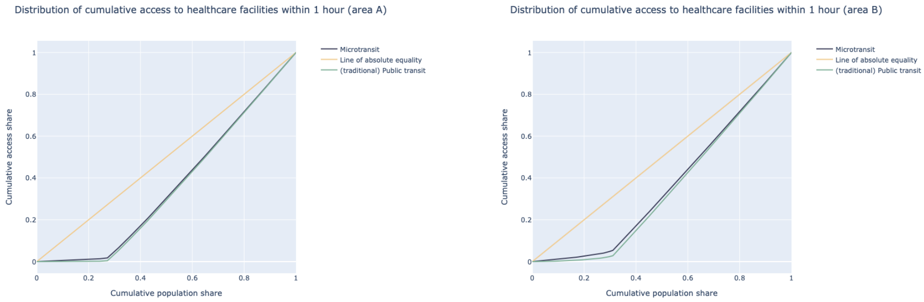
Area	Category	Gini without microtransit	Gini with microtransit	P-value	D-statistic
A	Healthcare facilities within 30 minutes	0.565	0.463	4.646813575507652e-07	0.47692307692307695
	Healthcare facilities within 1 hour	0.291	0.277	0.0010683738044752586	0.3384615384615385
B	Healthcare facilities within 30 minutes	0.518	0.347	9.838707770131476e-13	0.4715447154471545
	Healthcare facilities within 1 hour	0.297	0.271	0.01224429848310399	0.2032520325203252

Table E.3: Gini coefficients before and after microtransit intervention and p-value and d-statisic to test significance of difference between the distributions for cumulative access to healthcare facilities.



(a) Area A. (b) Area B.

Figure E.5: The Lorenz curves showing the distribution of cumulative access to healthcare facilities within one hour.



(a) Area A. **(b)** Area B.

Figure E.6: The Lorenz curves showing the distribution of cumulative access to healthcare facilities within one hour.

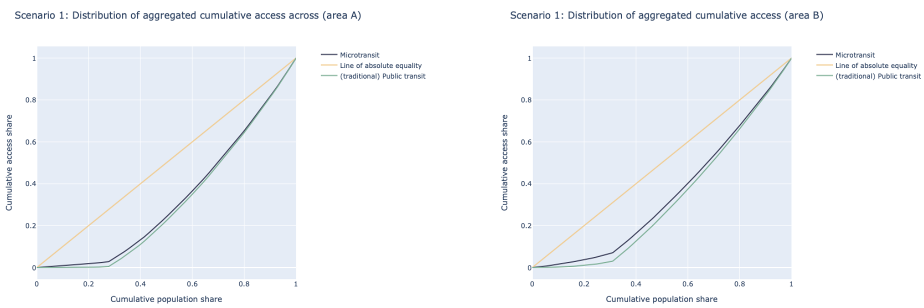
E.4 AGGREGATED ACCESS

In accordance with the scenarios listed in Section 5.4, the Lorenz curves, Gini-coefficients and statistical significance levels are shown again here.

Table E.4 shows that for both areas aggregated access for scenario 1 has a highly significant p-value. For both areas, the p-value for scenario 2 is not significant. For area A the p-value for scenario 3 is not significant but the p-value for area B is significant.

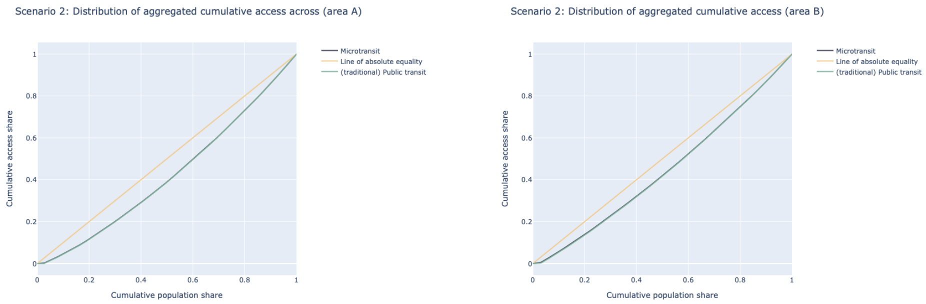
Area	Scenario	Gini without microtransit	Gini with microtransit	P-value	D-statistic
A	Scenario 1	0.372	0.346	8.103639238 0976e-05	0.39682539 68253968
	Scenario 2	0.156	0.154	0.033977965 666600246	0.25396825 396825395
	Scenario 3	0.684	0.016	0.019962099 95982694	0.26984126 98412698
B	Scenario 1	0.347	0.302	0.003310918 8672936917	0.22764227 642276422
	Scenario 2	0.119	0.115	0.143701266 92535368	0.14634146 341463414
	Scenario 3	0.477	0.045	0.000732476 5123110958	0.35483870 96774194

Table E.4: Gini coefficients before and after microtransit intervention



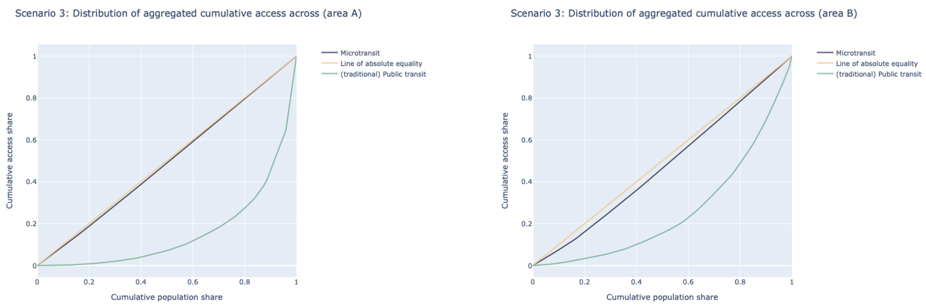
(a) Area A. **(b)** Area B.

Figure E.7: The Lorenz curves showing the distribution of aggregated access for scenario 1.



(a) Area A. **(b)** Area B.

Figure E.8: The Lorenz curves showing the distribution of aggregated access for scenario 2.



(a) Area A. **(b)** Area B.

Figure E.9: The Lorenz curves showing the distribution of aggregated access for scenario 3.

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COLOPHON

This document was typeset using LaTeX. The document layout was generated using the arsclassica package by Lorenzo Pantieri, which is an adaption of the original classicthesis package from André Miede.