Master's Thesis

MSc Energy for Smart Cities

Microtransit for urban mobility: analysis, case study proposal and potential environmental impacts

REPORT

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Convocatòria: September 2018

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Abstract

The sector of transportation accounts for 28% of all worldwide GHG emissions, the majority of them being CO_2 (EPA, 2018). In densely populated areas, public transportation has proven its potential to increase the efficiency of mobility and reduce traffic and GHG emissions. However, in less populated areas, outside of main activity centers and busy corridors, fixed-route public transport has shown an inability to meet the requirements of low and scattered demand for transport. This thesis assesses microtransit as an alternative to fixed-route transit services in these areas. The present study carries out an analysis of public transport and microtransit from a purpose point-of-view, to evaluate the ways and contexts in which microtransit can become a complementary mean of transport to enhance the overall efficiency of entire mobility systems. This thesis proposes a case study in the outer metropolitan area of Barcelona to evaluate the potential traffic and GHG emissions reduction of the implementation of microtransit in a number of municipalities with a proven lack of public transportation availability and high private vehicle dependency. Here, the main characteristics of the microtransit service to become effective in the specific area of implementation are explained. A comprehensive transportation data analysis shows that traffic and CO_2 emissions savings are moderate (about 10% traffic reduction and 5% CO_2 emissions savings), though, the proposed service also contributes to decreasing isolation and enhancing collective transit coverage and accessibility in the area of implementation.

Keywords: mobility, transportation, public transport, microtransit, on-demand transport, public flexible routes, GHG emissions, sustainability, environmental impact, ride-sharing, vehicle-sharing.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Transportation is one of the most readily changing sectors today. With the rapid spread of IT-enabled services and the high penetration in our society of smartphones with internet connection and geolocation services, an opportunity has come up for companies in the sector to enhance and innovate upon current transportation infrastructure.

Ride- and vehicle-sharing services are sprouting all around, making a more efficient use of low occupancy private vehicles to offer flexible mobility at affordable prices. However, the use of live location data and internet connectivity has not yet been widely implemented in public transit.

Microtransit has arisen as a collective transit system that aims to offer the flexibility of connected ride-sharing services while featuring the higher vehicle occupancy rates that traditional public transportation means offer.

Several companies are offering different interpretations of microtransit services with different degrees of success. The implementation of this mode of transport, though it offers many advantages and technological progress, is not adequate in every urban context. Same as it occurs with other means of transport, one must analyze what purposes each mode of transport is best for (i.e. one would never invest on a subway system in a low population urban area).

The present report carries out a purpose-oriented analysis of the mobility sector and thoroughly assesses microtransit. This study evaluates how and in what contexts microtransit can fit into the transportation sector, taking into account the advantages that it offers and the challenges it supposes.

To further measure the findings and conclusions made in the report, a case study is proposed for the outer metropolitan area of Barcelona. Here, the urban areas that match the studied conditions for an adequate deployment of microtransit services are identified. Then, a micro-transit service proposal is explained that fits into the specific characteristics of the identified urban areas.

Lastly, a comprehensive mobility data analysis of the proposed area of study is performed. The potential penetration rates in the transportation supply spectrum are studied and calculations about potential traffic reductions and Greenhouse Gas emissions savings are carried out.

1.1 Objectives of the project

The following list outlines the objectives of the project:

- Examine the transportation sector in urbanized areas, as a pillar of smart cities initiatives. Its purposes, its problems, and its future trends.
- Analyze on-demand microtransit as a collective transportation alternative, identify the mobility needs that microtransit must cover and determine the contexts in which microtransit can be successful to improve the overall transportation quality of an urban area.
- Propose a service of microtransit for the greater Barcelona metropolitan area that increases the accessibility of public transport and improves the overall transportation standards of the area.
- Retrieve detailed mobility information and propose a methodology to treat such information to analyze the outcome of the proposed microtransit solution in terms of traffic reduction and environmental impacts.

1.2 Scope of the project

The field of study of this project is the transportation sector, in particular, microtransit. The present document studies the transportation sector from a purpose point of view and evaluates why different modes of transportation are implemented upon the necessities of different societal and geographic contexts. This study makes theoretical findings about the transportation sector in general and then explores the sector of microtransit in detail. Particularly, the project explores why microtransit is becoming an important alternative for collective transportation at this point in time, what are the characteristics of this mode of transport that improve the current mobility means and what are the challenges of microtransit than can result in negative impacts in transportation.

For the research of transportation and microtransit, this project reviews public domain literature, papers and studies; and interviews transportation planning executives in the public sector (public transportation agencies and transportation departments of municipalities) and private companies in the transportation and microtransit sectors. This way, the study can have a comprehensive understanding about the necessities that public entities identify regarding mobility, understand what are the current developments in private company transportation and how they are trying to answer to current mobility challenges by utilizing breakthrough technologies and business models.

The present study proposes a case study to evaluate how the findings and conclusions about microtransit can fit into the conditions of a real geographic, mobility and population context. Here, the project explores how the gained insight about an adequate microtransit service can serve to design a specific microtransit system upon the particular characteristics of a certain area.

This project delves into how to assess the potential effects of a new transportation service, regarding traffic reduction and potential environmental impacts, analyzing comprehensive mobility data for a certain designated area.

Chapter 2

Transport in cities

This chapter examines transportation in cities from a purpose point of view. Here, the goals of transportation, depending on what kind of mobility is intended to be offered in urbanized areas, are analyzed. The lifestyle of individuals in our society determines the transportation needs of each. Therefore, mobility services are supplied, designed and implemented in cities as an answer to citizens' requirements. For example, one should not see a high-capacity long-distance train passing by a little town where such connection is not needed, or many full wheel drive vehicles in a heavily urbanized area with good weather and plain orography.

A pillar of smart cities initiatives is to offer greater quality of life while limiting negative impact on the environment and minimizing our resource usage. If this is extrapolated to the field of transport, one must analyze how citizens can use transport services without building entirely new infrastructure or manufacturing more vehicles.

In the 20th century, when transportation of all kinds started to take off (motorized cars, motorbikes, trucks, planes, trains, metro, etc.), the philosophy behind offering better transport was based on expansion, namely, building more roads and railways, and mass producing motorized vehicles. In the first half of the 20th century, there was not much conversation about global warming and environmental conscience in the infrastructure and manufacturing industry. Long and wide highways were being constructed that connected multiple cities and created a more cohesive society, as people were less isolated. Nevertheless, roads soon started to be filled with cars, in and out of the main metropolitan areas. With this, smog became a threat in greater urbanized areas that were filled with roads and cars constantly polluting. In the 1950s, studies about the perils of car pollution and smug were starting to be carried out (SCAQMD, 2018), and society started to gain conscience about the negative impact of transportation activities on life and on nature.

On top of this, mobility in cities is becoming increasingly difficult due to drastic population changes. In the 1950s, 30 percent of the worldwide population lived in urbanized areas. Today, more than half – 54 percent – live in urban areas; and by 2050, 66 percent of the people will live in cities (UN, 2014). If one also takes into account the fact that worldwide population will increase by 2 billion in the coming 25 years (Roser & Ortiz-Ospina, 2017), to manage the mobility of such an increased number of people in smaller and denser areas will become a much more complex challenge.

At the same time, people's mobility behavior has changed, together with quality standards. Citizens have an urge for immediacy that transport needs to satisfy. Spatial barriers are being overcome as transport is becoming safer and faster.

Transportation today, must not only offer a direct utility (to offer mobility services to citizens). It must offer it in a way that its activities' impact on the environment is minimized. Therefore, the way transportation is designed today must be different than how it was designed before.

2.1 Goals of transport in cities today

With the surge of worldwide population and the migration of people towards urbanized areas, together with all the environmental challenges we face today, the goals of transportation in cities must be well defined and prioritized. The following list outlines the goals of transport in cities the present report deems most relevant:

- **Mobility**: Offer safe, convenient and accessible transportation of people and goods.
- **Sustainability**: Design infrastructure and services for transport that respect the environment and contribute to fighting against climate change and environemntal conservation.
- **Economy**: Provide a transportation system the supports the city's and regional economy, enabling high connectivity, safety, reliability and affordability.
- **Equity**: Provide all citizens with the right of having a transportation system that covers al basic mobility needs. Mobility must be affordable for citizens of all types, it must be accessible for most, regardles of their grographic area within the urban environemnt and regardless of their condition (disabled, under-aged or elderly).
- **Technology**: Make use of creative and technical development in transportation, communication and information technologies to provide high-quality, low energy-intensive and efficient mobility services.

2.2 Transport planning purposes

The previous list explains the general goals that transport must try to reach. Then, one must look into the specific traits of each city and population, to plan clear objectives that follow the goals. Objectives must be achievable and concrete, whereas goals represent the targets to aim for.

To achieve these objectives, city transport planners look at two general purposes of transport and decide on a balance between both, depending on their specific policy preferences. These two purposes are **ridership and coverage**, and they are paramount when analyzing transport supply in a city. Ridership refers to how many people use a specific service and coverage measures accessibility and social equity of transport. The following paragraphs explain further these two concepts and what factors have an effect on them.

2.2.1 Ridership

Environmental and economic sustainability are key factors when designing a public transportation network. Ridership considers how many people use a public transportation service. Its economic and environmental success is based on the number of people that use it. As the usage of collective means of transport goes higher, more money can be collected by usage fees. At the same time if a higher number of people use a collective transport service, fewer car trips will typically be generated, hence, much less CO_2 will be emitted to the atmosphere. In urban areas, on top of emitting less CO_2, fewer cars will consequence in better air quality and better health and living standards for its citizens.

Ridership is typically measured by looking at how many passengers use a service per every kilometer covered (**passengers/km**) or by how many persons use a service per every hour of operation (**passenger/h**).

(Walker, 2008) explains the public transportation services designed with ridership goals in mind:

- *Constant all-day services* in the most transitted and dense areas. This can normally be seen in the center of urban areas where there are many pedestrians and gridlock is frequent. Citizens tend to make high use of the public transport in these areas and ridership is very high.
- *Main connection routes* between major activity areas are designed for high ridership. Public transport that connects during all-day periods in areas where many economic and leisure activities take place are massively used, and therefore designed to accommodate many users.
- *Services for commuting* during peak mobility periods during the day, namely in the morning and in the evening. These services are specifically designed with ridership purposes in mind, to supply massive mobility needs during commuting.

Collective transport services that offer capacity for ridership goals are those that require the most initial investment and offer highest capacities. These are commuter trains, long articulated buses, metros and trams.

2.2.2 Coverage

Collective transport must also take into account a social and accessibility purposes. The goals of coverage are related to the availability of service for different population segments and geographic areas inside a designated area.

The transportation services designed with coverage goals in mind tend are explained in (Walker, 2008):

- Specifically implemented public transit routes to support the needs of *disadvantaged populations*. These can be, amongst others, senior citizens, disabled persons, those with no driver's license, etc. If these transport routes were designed with ridership purposes in mind, they would probably be canceled, because of low usage rates. However, the purpose of these is to create social equity and accessibility for a larger percentage of the population.

- Transport services for *geographic equity.* For the scattered areas with low population density, to implement a service expecting high usage rates is not viable. However, city transport planning must also consider these segment of the population, and they should have accessibility to the public transportation network.

To measure coverage goals, one must look at the percentage of population serviced by a public transportation route or network. This is normally measured by the percentage of population and jobs within a certain area of service, measured in kilometers or meters.

The most common transportation modes that are implemented with coverage purposes in mind are regular buses, smaller neighborhood mini- or micro-buses and taxis.

2.3 Traditional modes of collective transport

With the goals and purposes of transport in mind, the following section explains the types of transport services that exist depending on the characteristics of each urban area, the lifestyle of its citizens and the purposes of transport.

Transport is needed when people require mobility. Need for movement is generated by the economy, where economic activities take place in different geographical areas, and transport supply must cover these needs. Economic and leisure activities are enabled by infrastructure built for those purposes in different geographical areas within a confined urban space. Without an adequate transport supply that connects people with their mobility needs, infrastructure would be useless (Rodrigue, Comtois, & Slack, 2016). Therefore, transport supply modes need to consider the kind of mobility needed and offer supply in accordance.

In the following paragraphs, different modes of transport will be identified and analyzed, depending on the population size and city layout. Population, economy and urban planning in cities determine the demand for public transportation. Then, supply must be offered to match and adapt to the demand's requirements. When looking at public transportation, if enough supply is not offered, insufficient demand will be generated (Rodrigue et al., 2016), and public planning will no be able to reach the ridership and coverage goals. However, if many public transport services offer excessive supply, the system may become economically unviable.

2.3.1 Suburban (commmuter) trains

Trains are a segregated mode of public transportation. This means that they have their own right of way, immune to delays by other modes of traffic. Rail-based transport systems have more capital and overhead costs than other modes, due to the necessity of having to build a whole infrastructure with the specific purpose of their sole operation.

Since their construction is costly, they generally offer the highest capacity for passenger transportation, which makes relative maintenance and operation costs for rail-based systems cheaper, because they can transport many people in fewer convoys and collect more fees per ride.

Suburban trains systems offer the highest capacity of passenger transit amongst all public transportation modes in a city. They are normally part of regional or national networks. They normally act as the connection with other urban areas and towns.

Operating speeds are very high and they cover long distances. Normally, these modes of transportation offer very high capacities and relatively low frequencies. Since operating speeds are high and distances long, to be competitive, there normally are few stops throughout the whole line. On average, passengers take longer than with other modes of transport (bus or metro) to get to the stop, but this excess of time to get to their stop is compensated by the reliability that these trains offer (because they operate segregated from other modes of transport) and the high speed.

The level of service is generally optimal. Plenty sitting spots are offered because travel times are longer than with other modes of transportation. Stations need to be spaced, which creates the need for good accessibility to the stations. To offer access to stations, adequate parking areas are normally offered where park-and-ride or kiss-and-ride services are normally offered by making it easy for commuters to park their vehicles at parking lots. However, this creates the risk of congestion at the entrances and exits of the parking lots during peak hours of the day. Nonetheless, bus feeders can also be offered, so that the need of a private vehicle is completely eliminated.

To build the train tracks and stations, if they are not built underground since they require much space, they incur the risk of excessively disrupting the urban fabric, which may lead to controversy.

2.3.2 Metro

The metro is a form of rail-based underground transportation service that generally offers transport inside city boundaries for the majority of its network. Unlike the suburban train, the metro has many stops along the way, which consequences in a slower speed to cover distances.

The metro uses a segregated right of way, with no other traffic modes influencing its operation. Therefore, although it usually has many stops along a line, it is a fast and reliable transportation service inside a city. Any delay or modification in their schedule can only be due to a fault in their own operation, or the workers and passengers interacting in it.

Most metro stations are built underground. This may lead to difficult accessibility if proper measures are not taken. Many stairways take passengers up and down to get them to metro platforms. For the elderly, disabled, or people in a wheelchair, this can become an impediment difficult to overcome, if ramps, priority ways and elevators are not installed.

Subway trains are often articulated by four or more convoys, making the metro a high capacity mode of transportation. Generally, metros are designed to have wide spaces for standees with vertical and horizontal long handles to make the rides safe.

Thanks to its high capacity for carrying many passengers in each train and its reliability and inside city speed, the metro can compensate for the high capital and maintenance and operation costs that it requires, due to the nature of the system. For the train tracks to be totally segregated from other modes of transport, the metro is built underground. This comes with enormous capital costs that need to be offset by many passenger usage fees for a long period of time.

2.3.3 Light Rail Transit

The LRT (Light Rail Transit) or tram is a mode of public transportation that operates on a semi-segregated right of way. It is partially separated from traffic, and at some points, it intersects other traffic routes and shares its space with are mobility means. When the tram is moving alongside traffic, it is normally given priority, slowing down other modes of traffic and making the tram faster and more reliable to cover distances throughout an urban area.

Its operating speeds are also slower than the metro and commuter trains. Although it is partially segregated, it still needs to share many intersections and urban areas, which makes transit less continuous. It is either formed by a single vehicle or articulated, and although it can carry many passengers at a time, their capacity is lower than that of the metro or commuter trains.

The tram is adequate for non-plan orography because it can withstand steep uphill and downhills and it can take drastic turns (English, 1995). This makes it a very adaptable mode of transport inside urban areas. LRT is electrically powered with an overhead cable that follows for the whole way.

With regards to accessibility, since LRT tracks and stops are at street level, they are generally easy to access for the elderly, the disabled, people in a wheelchair and children. When planning where to install tram stations, one must look at the characteristics of the street and traffic passing by, to create an accessible environment.

2.3.4 Bus transportation

Unlike all the previously explained modes of transportation, buses do not have a segregated right of way, which means that they are competing for space with all other modes of transport that travel on roads; namely, other buses, private cars, motorcycles, bicycles and, at times, pedestrians.

This lack of segregation can create more unreliability because the bus system can be altered by any external traffic factor. This can create bus bunching, congestion, and delays, which can make the bus system less attractive.

Bus stops are at street level, making them quite accessible. Some bus stops are covered and have seats, and some others consist of a sign indicating a bus stops there and they are completely exposed to the weather, which in colder and rainier cities can be a problem. Some stops have limited timetable information for passengers, and some others display no information. Stops do not have a fare collection machine. Therefore, fares must be bought inside the buses, by having the driver collect them. This increases delays and decreases comfort for passengers.

Passenger-carrying capacities are lower than those of train transportation modes. For around sixteen meter long articulated buses, capacities can be around 100 people with a lot of standing space; ten to twelve meter long regular buses have capacities of 50 people and seven-meter long mini- or micro-buses can offer capacities of 16-20 passengers (English, 1995).

As previously mentioned, one of the most important problems of bus-based transportation is that they do not travel on segregated rights of way. This is being solved with BRT (Bus Rapid Transit) solutions, where articulated (or non-articulated) buses travel on exclusive designated bus lanes or ways. This way, higher quality standards can be achieved by offering higher capacities in a more comfortable and cost-effective manner. BRT intends to combine the reliability, convenience and speed similar to the metro's or tram's, with the cost reduction of bus-based systems (ITDP, 2018).

2.3.5 Usage of public transport in a city

Public transportation can come with high capital costs, especially underground systems, and operation and maintenance costs that can burden the economic viability of a system. High ridership, many people using a system, can offset these costs, whereas the modes of transport that carry few passengers, must have a coverage purpose (social and geographic equity and accessibility for citizens) or it will become pointless and expensive. For this reason, is paramount to have in mind for what purpose one specific system is being designed depending on the characteristics of a certain urban area.

Generally, operation and maintenance costs can be offset with high capacity services with low frequencies. These cases are designed for ridership purposes, as explained in 2.2.1.

The following figure shows a typical urban area layout that will be used as an example to show how the different modes of transportation explained before can interact to create a coherent network. Naturally, not all cities are organized in a radial-circular manner, but most do share the density area separations that the following figure represents.

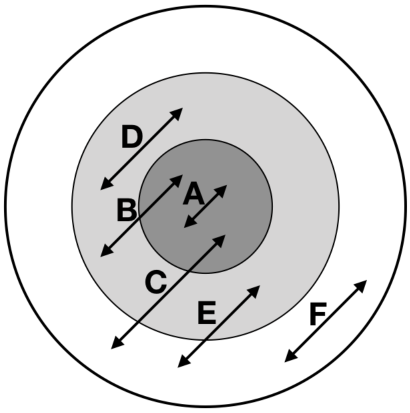

Figure 2.1: Representation of different density areas in a city and the possible urban journeys. [Source: (English, 1995)]

The darker area in figure 2.1 represents the highest density areas in a city, the lighter one represents medium density areas and the white zone shows the low-density areas. The arrows, labeled with different letters, represent the possible journey one can take from different density areas within a broader urban area.

Journeys within high-density areas (**Arrow A**), can be made with metro, trams or articulated buses. Those modes of transport with high capacities and ease of access are the most recommendable (English, 1995). These modes create little traffic congestion in the densest areas, where economic and leisure activities are intensive. Suffering congestion in these areas can lead to severe economic hindering, health problems for by-walkers due to excessive CO_2 emissions by motorized vehicles and a decrease of quality of life.

Between high and medium density areas (**Arrow B**), public transportation modes such as suburban trains, metros, and articulated buses are recommendable. These modes can cover long distances in a shorter time (especially the rail-based modes).

For trips throughout medium density areas (**Arrow D**) and from low to medium density zones (**Arrow E**), there is normally longer and extended areas to cover. In these cases, smaller and more flexible vehicles are more recommendable for public transportation. Metro is a viable option, but due to its high capital costs, it will not be able to cover as many medium and low-density areas as more varied bus routes. Therefore, regular buses that take longer and more meandrous routes can be a more effective and cheaper option. In less dense areas, the passenger volume is not as high as in the high-density areas, so public transport modes are not so limited by the necessity of carrying large volumes of people.

For those longer trips between low and high-density areas (**Arrow C**), commuter trains and longer metro lines tend to be the most suitable. The volume of passengers in these trips can be high (especially during peak hours of the day, when workers commute), so high capacity transport modes suit better these journeys. In the least dense and larger areas, small bus feeders or adequate infrastructure for park-and-ride are needed (see section 2.3.1) to connect dwellers with their area's main train stations.

Journeys throughout the least dense urban areas (**Arrow F**) are generally the least economically viable, because of the low ridership they usually attract. They are implemented with coverage purposes (see section 2.2.2). These journeys have traditionally been discussed amongst public transportation planners to find the right formula to establish an economically viable option that offers high accessibility standards at a low cost. Today, many low-density areas are covered with bus services that are generally underused. There are some flexible transportation alternatives that could potentially be more beneficial for these cases, such as, demand-response services, collective taxis, carpooling, car sharing, etc., that can be looked at to offer a better and more economically viable service (Ribeiro & Rocha, 2013).

2.4 Alternative collective transportation

This section identifies and briefly explains the alternative or new services of collective transportation that are being analyzed or implemented in cities. Nowadays, public transport planning entities and several companies in the private sector are looking into **shared mobility** solutions to increase the level of service of collective transport. As explained at the beginning of chapter 2, nowadays transportation standards and quality are trying to be increased by designing services that use the existing infrastructure to create better transport, instead of a basing improvement on expansion (more cars, wider roads, etc.). With this philosophy, many shared mobility services are being implemented today, such as vehicle-sharing, ride-sharing, ridesourcing, microtransit, etc.

In the coming paragraphs, different modes of shared-mobility transportation will be analyzed. To have a clear idea of how to conceptually organize the different modes of transportation that will be explained. (Jin et al., 2018) show a very interesting diagram that organizes in types and categories the most discussed modes of shared-mobility transport.

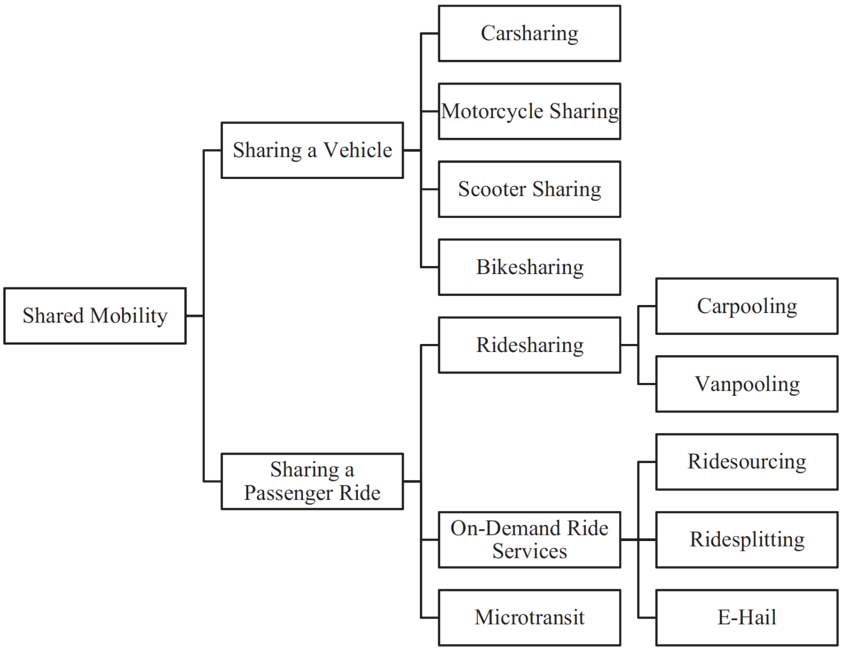

Figure 2.2: Categories of shared mobility. [Source: (Jin et al., 2018)]

Figure 2.2 divides shared mobility into two main categories, those services where a vehicle is shared, and those where passenger rides are shared.

2.4.1 Sharing a vehicle

Vehicle-sharing services are those where a private or public entity rents their private vehicles out for a short period of time. This time period might be of minutes, hours, or days. Sometimes, rental time and price are fixed from before, which is the operation mode of traditional **car rental companies**; and sometimes there is a per-minute price set and the customer pays at the end, depending on for how long they have used the vehicle.

This second business model is often seen in the newer car and motorcycle per-minute rental companies that have a phone application based system with live location tracking, to monitor the time and location where their vehicles are being used, and by whom. In these cases, vehicles are parked throughout metropolitan areas and they can be accessed by customers by unlocking them with their smartphones when they are close to the vehicles.

The objective of these services is to complement or substitute public transportation and to decrease dependency for owning private vehicles. Ideally, vehicle sharing services can make people not depend on their own vehicle to make point-to-point flexible journeys. This would result in fewer vehicles on the streets, more parking spaces and more efficient and utilized vehicle fleets altogether.

One can identify two different types of vehicle-sharing systems in urban areas (Schmoeller & Bogenberger, 2014):

- Station-based systems: vehicles are always in the same station and must be returned to that same station after usage.
- Free-floating systems: vehicles are placed in empty parking spots throughout a determined urban area and they can be picked up and returned anywhere inside that given area.

For the free-floating systems, an additional problem arises with the positioning of the vehicles to make the system effective. If vehicles are positioned by the operator, they will be close to public transportation stops, and the most common departure or destination sectors in cities. However, vehicles are often parked where the last user has left them. This can become a problem, especially, if vehicles are parked in areas where there is little demand, so there is the risk of having underutilized vehicles. This becomes even more problematic when the shared vehicles are electric and need to be charged often and in specific charging points. There are many studies, such as (Bruglieri, Colorni, & Lue, 2014) – where they study case an electric shared vehicle relocation problem in the city of Milan – that analyze methods of relocation, to make the shared vehicle fleets more efficient.

Nowadays, there are many car and motorcycle sharing companies in many major cities in the world. Some are station-based and some free-floating. There are those that utilize vehicles of private people (acting as platforms where individuals can rent their vehicles for short periods of time) and those that rent company-owned vehicles.

For example:

- Free-floating, company-owned vehicles: *DriveNow* and *Car2go* are two European (German) companies that offer daily or by-the-minute prices.
- Station-based, company-owned vehicles: *Bluemove* (European) and *Zipcar* (North American) offer hourly, daily and fixed fees.
- Station-based, private vehicles: *Turo* (North American) and *Drivy* (European) act as platforms to connect people who want to share their vehicles for short periods of time.

As previously said, there are many **motorcycle sharing** companies that are operating in many cities. Since motorbikes have fewer problems than cars for parking, motorcycle sharing services are generally free-floating and charge by-the-minute. Car-sharing services target both short and long journeys, and therefore offer rates for longer periods of time. Since motorcycles are more adequate for shorter in-city journeys, operators offer by-the-minute rates, with no fixed fees. Some of the major motorcycle-sharing companies around are *Coup* (Berlin and Paris), *Cityscoot* (Paris and Nice), *eCooltra* (Barcelona, Madrid, Lisbon and Rome) and *Yugo* (Barcelona and Bordeaux).

Various **bicycle- and scooter-sharing** services are sprouting in many cities in Europe and in North America. These services are clearly intended for short journeys inside cities, shorter than two miles in the case of electric scooters (Kelleher, 2018). These services are the most environmentally friendly of all. All vehicles are either human-powered or electric, they occupy the least space on the street and use up the least resources to manufacture. But as mentioned, they have distance and range limitations.

2.4.2 Sharing a passenger ride

Figure 2.2 classifies passenger ride-sharing into three categories: ridesharing, on-demand ride services, and microtransit. Vehicle-sharing initiatives intend to increase the overall efficiency of a fleet of vehicles. Passenger ride-sharing intends to increase the occupation of passengers per vehicle for a specific ride. Hence, with fewer vehicles, more passenger rides can be carried out.

Ridesharing

Ridesharing services are those vanpooling and carpooling activities where specific rides are shared by people who have similar origins and destinations. Carpooling has been around for decades, especially in suburban areas where public transportation accessibility is low and neighbors have traditionally self-organized to cover rides to and from work in fewer vehicles, hence, saving fuel and vehicle maintenance money.

Lately, there have been several companies that enable carpooling in a more standardized and pre-regulated manner. *Bla bla car*[1] is a clear example of a company that has served as a platform for carpooling. They connect people who already have planned trips and empty spaces in their vehicles, with people that could take advantage of that ride, paying a fare that the vehicle owner decides within a predefined range *Bla bla car*.

Another ridesharing company worth mentioning is Didi Hitch[2], arguably the biggest ridesharing company in the world, in 2015 they serviced over a billion rides, whereas Uber[3] needed 5 years to achieve that volume (Hawkins, 2016).

Ridesharing is a more environmentally friendly option for commuting. It increases car occupancy rates, it decreases the number of cars on the roads (especially during commuting hours, when congestion may become a significant problem) and it, therefore, it reduces CO_2 emissions in the transportation sector.

On-demand ride services

On-demand ride services can be divided into three different categories: ridesourcing, ridesplitting, and e-hail, as Figure 2.2 shows. Ridesourcing refers to the phenomenon of connecting private drivers with passengers that request rides via smartphones and applications (Jin et al., 2018). Ridesplitting also connects people via a smartphone application but its finality is to share a ride that the private vehicle owner was already going to make and costs can be split (similar to ridesharing). Lastly, e-hail is a regular taxi service, only drivers and passengers are connected via their smartphones.

The following paragraphs discuss some aspects of on-demand services:

Although on-demand ride services seem like a modern alternative to better transportation standards and improve means of collective transport, one must look at the context in which on-demand solutions might be implemented. If passengers decide to use ridesourcing apps, i.e.

[1] French transportation company founded in 2006 (BlaBlaCar, 2018)
[2] Chinese company founded in 2012 (Crunchbase, 2018c)
[3] North American company founded in 2009 (Uber, 2018)

Uber or Lyft[4], one should analyze what other modes of transport that person would have used before the existence of these ridesourcing modes. In denser cities with extense public networks (such as London or New York), it is likely that before the existence of Uber, users would have taken a public transport mode, which eliminates the suffering of congestion and the hassle of parking. In these cases, ridesourcing would be creating more traffic and congestion, and therefore increasing pollution. On the other hand, in less dense cities and in more rural areas where car dependency is higher, ridesourcing may substitute other car trips. In these case, ridesourcing can have a positive impact by potentially decreasing car ownership, because people find a convenient alternative to having to drive.

Another aspect of on-demand ride services that can create controversy is whether it competes or collaborates with public transportation networks. As said in the paragraph before, in those cases where users decide to use ridesourcing modes instead of public transport because they deem it a more comfortable solution, ridesourcing is a less environmentally friendly solution competing with public transport. However, it has been proven that on-demand services can effectively collaborate with public transportation for the benefit of both modes of transport. In Southern California, six new stops were added to a train line going towards downtown LA. It was observed that Uber pickups within 100 meters from the train stops surged substantially, indicating that passengers combined both modes of transport (Williams, 2017). In the same way, in London, the underground expanded some services during the night time. During the night, Uber rides starting within 200 meters from the underground stops increased by 22% (Rao, 2016).

The issue of possible discrimination towards some segments of the population has brought some controversy as well. It has been studied that ride-hailing adopters tend to be the younger, wealthier and more educated segment of the population (Clewlow & Mishra, 2017). The *digital divide*, which refers to the accessibility difference between those are familiar with information and communication technologies and those who are not, can increase with ride-hailing services that only work via phone applications.

In on-demand transportation, it is mostly private companies who have access to private information of private users and many of their movement patterns. This sensitive information needs to be correctly handled. There is the risk of how this data is used or to who is leaked.

On-demand ridesourcing services have appeared as a job alternative for many in need of one. It supposedly offers a better quality transportation alternative that creates jobs. These jobs are said to come with schedule and working time flexibility. Although this style of work does have these benefits, they also give up other benefits that regular employment offers, such as paid vacations or medical insurance (Smith, 2016).

Microtransit

Microtransit refers to private and/or public shared transportation that offers dynamic flexible routes and schedules to match demand more efficiently (MaRS, 2016).

Amongst the other passenger ride-sharing solutions that Figure 2.2 shows, microtransit can be regarded as the most environmentally friendly, in that larger capacity vans and microbuses are used and rides are sourced to be shared. Namely, each ride is not exclusive to a single demand

[4] American transportation services company founded in 2012 (Shontell & Lebowitz, 2017)

(such as Uber or Lyft). With microtransit, several users with similar routes share rides in the same vehicle. This decreases the number of vehicles on the roads and increases average occupation rates.

As it happens with other vehicle-sharing and on-demand ride services, microtransit takes advantage of the technologies available today (powerful smartphones, internet connectivity, GPS tracking, etc.) to offer tailored services of real-time dynamically moving vehicles. Without the mentioned technology advancements, this service would not be implementable today.

Microtransit can be private, public or local governments and private entities can collaborate working at cross-purposes. Public-private partnerships can be beneficial when they combine resources to offer a service that will increase accessibility and ridership performance of a transport system. However, these type of collaborations tends to be slow to execute. Privately promoted endeavors can save the public from infrastructure costs, but there is the risk of competing with public transportation instead of collaborating, and therefore potentially increasing GHG emissions and congestion.

Microtransit services can come in different forms of sophistication, depending on the context in which they are applied. In some cases, the route is partially flexible, always following a predefined broader route and timetable. In these cases, powerful routing and optimization software are not so needed. In other cases, routes and schedules are completely dynamic and flexible inside a broader designated area. A robust software capable of taking many more variables is more necessary in these cases, to correctly place supply where demand requires it.

More about microtransit is explained in the following chapter.

2.5 Context of transport in smart cities

Many transportation services today heavily rely on twenty-first century's technology and infrastructure and need to adapt their service to the quality standards and environmental requirements of the present. Therefore, transportation network agencies and companies today have the challenge of constantly improving their service to achieve consumer satisfaction, while at the same time having more support than ever from third-party technologies.

One of the pillars of smart cities' holistic approach is the empowerment of citizens by offering more information about city services and making citizens an active stakeholder to shape the way cities function, including transportation services. Traditionally, rail-based transportation means, i.e. trains or metros, have been well scheduled and arrival and departure times have been well predicted because they operate on segregated rights of way (see Section 2.3). This is one of the reasons why these modes of transport have traditionally had higher ridership than buses. Nowadays, the performance of bus-based systems is increasing because consumers require a more precise prediction of arrival and departure times. Transportation providers can live up to these requirements thanks to geolocation services and internet coverage.

These additional features can be seen as services that transportation companies outsource to public infrastructure providers, third-party technology, and telecommunication companies and to consumers themselves. Thanks to the fact that high percentages of the population have smartphones, especially in advanced economies (Poushter, 2017), and consumers have internet service contracts with telecommunication companies that they pay for, transport providers can offer high-quality service to consumers.

From a broader perspective, fast developments in computational power and large volumes of data analysis are becoming immensely useful for tailoring supply by analyzing demand trends more accurately than before.

With regards to offering transportation means and systems that respect the environment and that are aware of the ecological footprint of their operation, important developments are taking place. The electrification of public transportation vehicle fleets is already happening. In Barcelona, by 2024, 80% of all municipal buses will be electric (Vanguardia, 2018). Bike lanes and bike sharing services are sprouting in cities worldwide, and smaller alternative vehicles, such as electric scooters and segways are becoming more common.

Driverless technology is the most unknown and disruptive factor of transportation in the coming years. Autonomous public vehicles could make a tremendous impact on service quality, accessibility and ridership performance. Labor costs account for more than 50% of all costs of operation – fuel, in comparison, accounts for less than 10% (Lee, 2015). Public transportation services will be able to run for longer hours and cover more distances without depending on people to drive the vehicles. At the same time, those unable to drive, such as children, the disabled or the elderly, may be provided with a mobility option they currently might not have.

In short, the transportation sector is undergoing rapid changes thanks to new technologies, and new quality and environmental requirements, which have come as an opportunity for many transportation providers to offer new services and better and more varied mobility options for citizens.

Chapter 3

Analysis of microtransit

Public and private collective transportation agencies are offering IT-enabled services to enhance transportation quality for users. Microtransit is the result of applying this kind of technologies into a more sophisticated way, that takes into account the requirements of consumers to offer supply in accordance.

Following the previous sections, this chapter explains microtransit more in detail as an alternative to fixed-route public transportation. To determine the scope of analysis in this section, the following **definition** will be used:

> *Microtransit is a mode of public or private collective transportation that uses mid-sized vehicles (such as microbuses, minibuses or vans) to offer flexible and dynamic transport routes that adapt to consumers' location and time requirements, by means of IT-enabled services that connect demand and supply in real-time to offer a consumer-tailored service.*

Figure 2.2, in Section 2.4 (p. 21) shows the category that microtransit falls into amongst all the other shared-mobility transportation services. Microtransit is a mode where rides are sourced, namely, there are no predetermined routes that a certain vehicle takes, the system finds optimal routes upon users' requests, thereby new unplanned rides are constantly being generated.

On another note, microtransit is different from other on-demand ride-sharing services (see Figure 2.2) in that users do no exclusively source a specific ride. In services like Uber or Lyft, for instance, when a user books a ride, the vehicle only services that user for the duration of the ride. In microtransit, contrarily, a mid-sized vehicle is responding and adapting to multiple requests at the same time and creates routes that cater all users needs in the most optimal manner using a single vehicle. Therefore, average vehicle occupation increases and fewer vehicles travel around urban space. Hence, pollution and congestion can be more effectively alleviated with microtransit, than with other smaller vehicle ride-sharing services.

3.1 Purposes of microtransit

In Chapter 2 the goals of transport today are explained. Transportation planning should be carried out by considering these goals within the context of each urban environment. Adequate modes of transportation must be deployed depending on their level of effectiveness depending on the characteristics of each mode of transport and the land in which they intend to be deployed.

As explained in Section 2.3, different modes of transportation (i.e. buses, trams, trains, etc.) serve different purposes in transport and are adequate for different situations. For example, metros and trains are designed to offer high ridership and direct and fast connections between far away locations. On the other hand, smaller coaches and taxis can offer a coverage service where metro and train railways do not reach.

In the same logic, microtransit is an adequate option to serve a specific set of goals. The following list outlines the main purposes of microtransit:

- **Coverage and accessibility**: Microtransit is a coverage driven mean of transport. Since it comprises smaller vehicles with flexible routes, it is adequate for underserved low-density areas where users are scattered and there is no optimal fixed line that can cater to the needs of a larger area.

- **Point-to-point flexibility**: one of the major drawbacks of public transport, that for many consumers outweighs many other possible advantages, is that in most cases public transport does not allow for the user to enjoy a direct ride from any location to the exact destination. Microtransit is able to close this gap by having flexible lines that adapt to users' specific location requirements.

- **First mile/last mile service**: related to the purpose above, microtransit can cover the first and last mile that fixed public transportation often cannot. Intermodality can be boosted to increase the ridership in a whole public transport grid, by having flexible routes and schedules that adapt to-the-minute to other means of transport.

- **Information source for new fixed routes**: by having consumers use microtransit services, their mobility patterns can be more accurately retrieved and analyzed. This information can be used to observe if there are certain mobility patterns that are large enough to deploy simple fixed-route modes that can cover mobility needs more effectively. This process is carried out today with less accurate surveys and predictions from transport agency planners that slowly iterate until they find more effective transport routes.

- **Ridership enhancement in coverage-driven routes**: coverage-driven routes inherently offer low ridership, hence they are economically unviable. Microtransit can increase ridership in these routes by reaching demand points that fixed routes cannot reach and by offering a more convenient service for higher numbers of people in those areas.

In relation to the last element of the previous list, the following figure shows the qualitative trade-off of ridership and coverage when planning public transportation. This is not a loyal representation of any particular case; however, it shows the tendency of what kind of service public transportation must offer depending on its aim.

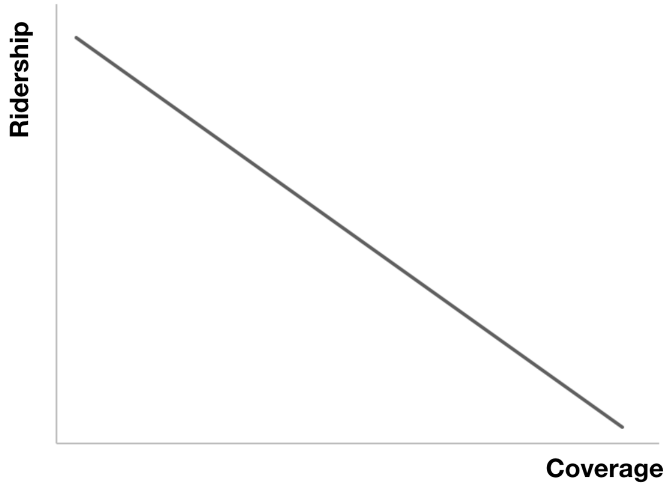

Figure 3.1: Qualitative trade-off between ridership and coverage.

On the top left side of the graph (Figure 3.1) one can find those means of transport that are thought to carry the most passengers (high ridership) in the densest areas of cities, such as city centers or activity intensive areas. These means of transport cover shorter distances, have frequent stops and carry more passengers at once. Towards the bottom-right side of the graph, those means of transport that cater to the least dense areas, where longer distances need to be covered and fewer people live are represented. The efficiency of these means of transport is low, and average vehicle occupancy is small. Smaller buses, inter-urban coaches and taxis service these areas.

The efficiency drops as more coverage needs to be offered because it is complicated for fixed-route collective means of transport to service optimally areas with low density and scattered demand. Fixed routes do not allow collective transport to adequately suit more people's needs.

Public transportation on the lower-right side of the graph is typically economically unviable. If these services were only driven by economic purposes, they would be suppressed. Nevertheless, since people who live in those areas have the right to be offered public transportation, municipalities and transportation agencies need to provide them mobility services. However, this service is often minimal and does not live up to adequate standards, because agencies do not want to spend excessive money on a system that will not report them benefits. Therefore, dwellers do not use public transportation and drive their own private vehicles. In a vicious circle, since few people use public transport, the benefits for agencies are lower and the service provided worsens.

This is a widespread problem in public transportation planning that has yet not been fixed. It is a significant problem too because the only alternative mean of transportation for low-density areas is the use of cars, which is the only private form of transportation that can run for long distances, provide flexibility and withstand adverse weather conditions.

Microtransit is capable of shifting upwards the ridership-coverage curve on the bottom-right section of Figure 3.1, to offer the same coverage and increase ridership at the same time. Figure 3.2 shows the potential gain in ridership that microtransit can deliver.

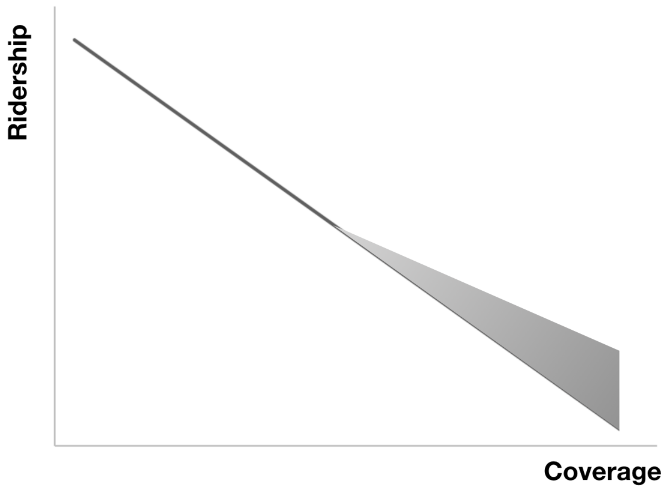

Figure 3.2: Influence of microtransit on the qualitative trade-off between ridership and coverage [Source: Conversation with private microtransit company, Shotl].

Figure 3.2 is a qualitative representation of the potential of microtransit to increase the number of passengers using public transportation in all those situations where coverage is prioritized. The main reasons why microtransit can increase ridership in this part of the curve are mostly explained by the list of purposes of microtransit.

The increase in ridership comes from a modal shift from private vehicles to microtransit. The point-to-point flexibility and schedule freedom that cars enjoy can also be at hand of users with on-demand services.

3.2 Applications of microtransit

This section outlines the applications for which microtransit is the most adequate option and can deliver more effectively than traditional modes of transportation. Most of these applications are directly related to the purpose of increasing ridership in coverage driven public transportation routes and schedules, see Figure 3.2.

Microtransit is predominantly effective when there are areas with low density and scattered demand, and in situations where a higher number of people need to take rides where many share schedules, origins, and destinations. The following table outlines the main applications where the context coincides with the two cases described in this paragraph.

1	Replacement of underperforming fixed bus routes
2	Shuttle and connection services
3	Off-hour travel time service
4	Specific services
5	Private company transportation

Table 3.1: Applications of microtransit

The following sections explain each application in further detail. One must remember that these are the most suitable cases for microtransit looking at the purposes of microtransit and the contexts in which it can become more successful than traditional modes of transport. There may be other application cases for microtransit, however, this section goes through the main and most representative cases that go in line with the theory and goals of transport (Chapter 2) and the purposes of microtransit (Section 3.1).

3.2.1 Replacement of underperforming fixed routes

As previously said, all citizens have the right to be provided with some form of public transportation. Those who live in city centers and in denser urban areas most times enjoy higher frequency and sufficient public transportation options. These come in the form of rail-based means of transport, such as trains and metros; or bus-based means of transport, such as high capacity articulated buses and smaller coaches as well.

Outside of city centers, public transport is covered by fixed-route buses. These areas tend to be extensive and demand scattered. Due to the nature of these dispersed areas, demand is most of the time low, so deploying several fixed bus routes to cover mobility becomes economically inefficient. Buses run empty, often unnecessarily consuming fuel and spending transportation agency funds on maintenance and operation of vehicles that are not giving the desired service.

The rigidity of fixed bus routes limit the coverage these services can give. Since distances are long, many people dwell far from bus transportation connections. The bus becomes inconvenient when the distance to the bus stop becomes excessive, which is very frequent in these areas. The following image is a graphic representation of the concept, where one can see the hassle for some people to walk to their bus stop.

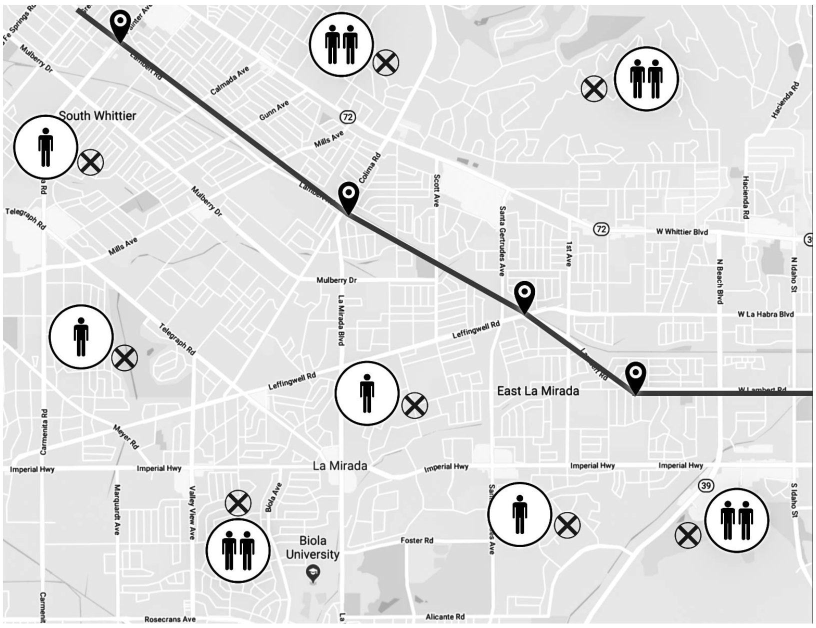

Figure 3.3: Representation of the limitations of a fixed route bus line

The *Journal of Transport and Land Use* in (Daniels & Mulley, 2013) carry out a thorough analysis of how long people walk in Sidney metropolitan area to get to their bus stop, and show that very few people walk for longer than one kilometer and the mean walking distance is 461 meters, which can be covered in less than 5 minutes. In these dispersed areas people often have their bus stop further than what they are willing to walk. Therefore, they decide to use their own private vehicles that generate pollution, congestion and decrease air quality.

To effectively offer transportation to citizens in these areas, several fixed-route bus lines could be deployed to increase the coverage area and become a more convenient option for many dwellers. However, too many fixed-route bus lines in low-density areas even more economically inefficient.

Flexible bus routes based on microtransit can more effectively cater to the needs of the people by adapting their routes, and therefore minimize the walking time for citizens. With a single bus, a large coverage area can be reached. The following figure shows a straightforward example of how microtransit can extend the reach of public buses and become a more convenient option for more users.

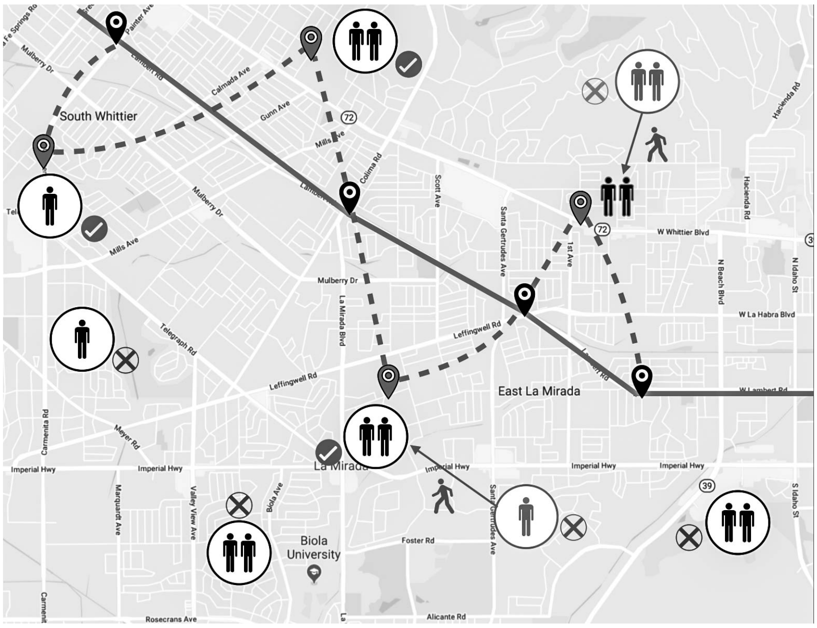

Figure 3.4: Representation of the increase in coverage of a microtransit based flexible bus route

Meandering public bus routes that constantly detour run longer distances than straighter fixed routes. This results in increased CO_2 emissions directly accounted to public transportation. However, the more extensive reach of these type of routes eliminates many unnecessary private vehicle trips. These trip savings far offset the little excess in pollution of the public buses and decrease congestion and pollution in urbanized areas.

A single microtransit bus can reach the coverage of multiple buses due to the nature of the area it is servicing. Since demand is low the bus will not have capacity issues and IT-enabled services will free the system from necessary infrastructure, and virtual bus stops can potentially be found all around the serviced area. On top of this, thanks to mobile devices and internet connectivity, trips can be requested life and the uncertainty of when the bus will arrive can be mitigated by offering a real-time prediction of arrival upon requests.

There are some examples today of transportation agencies that have replaced some of their routes in favor of microtransit solutions. Arlington, a city in the US, has replaced a fixed-route bus line with a microtransit solution, partnering up with Via[1]). They expect to increase coverage of public transit with less money (Bliss, 2017). In Sant Cugat (Barcelona), a fixed-route bus line has also been replaced by an on-demand microtransit solution, in partnership with Shotl[2]. In this case, the implementation of a microtransit service has been done with the objective of replacing a bus line and providing a connection service to the commuter rail. Below, one can read more about shuttle and connection services of microtransit.

3.2.2 Shuttle and connection services

Intermodality is a major application of microtransit. As explained in Section 3.1, traditional means of transport struggle at offering quality first and last mile transportation. In suburbs, outskirts and towns near to larger cities there is a large number of people that commute to the city every day. Many of these do not live close to a major public transportation stop that can carry them into the city fast.

For commuting purposes, the majority of the public transportation from outside and into the city, and vice-versa, is covered my longer distance commuter trains and subways that act as fast connections between the suburbs and city centers (See Section 2.3.1 for in-detail explanation). Those who live close to main commuter train stations, enjoy a fast ride to city centers. However, those who live further may not find it convenient to travel to the train stations to make their rides to work and back.

Nowadays, some fixed bus lines exist for the purpose of bringing people to these train stations. At the same time, often one can find built infrastructure (i.e. parking lots) for park-and-ride purposes (see Section 2.3.1). These two are solutions that can be of help for only a segment of the population. Those who live far from these fixed-route buses and those who do not own a vehicle are isolated from the commuter trains.

Microtransit can act as a shuttle service for this population, especially during peak hours of the day. Commuters can request their ride via IT-enabled services, and flexible bus routes can be created to pick commuter up at nearby corners from their home and drop them off timely, to get a quick ride into the city. A reversed service can be offered during the evening, to bring people from the trains station to their homes.

[1] A New York based startup
[2] Sant Cugat based startup

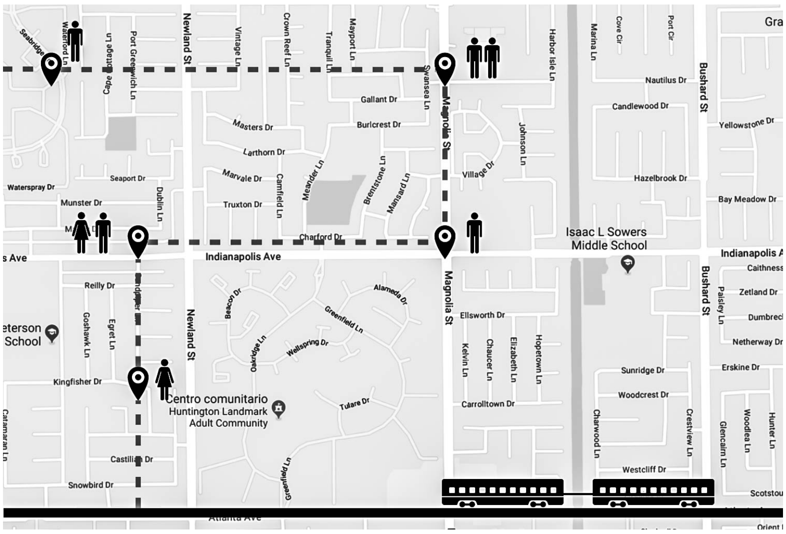

Figure 3.5: Representation of a microtransit shuttle service example.

The previous figure is a representative image of how an on-demand shuttle service could look like, in a very simple manner.

During commuting hours of the day, the mobility problem in urbanized areas is acute. The main entry and exit arteries of cities are gridlocked and many people lose excessive time stuck in traffic jams. Air quality decreases as pollution increases, and cities' transportation capacity is overloaded.

Throughout the present document, it has been said several times that microtransit falls into the coverage-driven public transportation category. Therefore, it is responsible for increasing accessibility and connectivity and often its social responsibility can be more important than the environmental. In this case, microtransit can play a significant role in reducing the environmental harms of cars during peak hours of the day, by drastically reducing the generated car trips and promoting a modal shift of many living on the outskirts from private to collective transportation.

3.2.3 Off-hour travel time service

Fixed-bus routes in periods of the day where demand is low and behaves at random for different locations and times are inefficient. During valley hours of the day and, especially, during nighttime, buses run empty and their operation becomes costly and ineffective.

During these times of the day, due to a low demand, the frequency of buses decreases significantly, and many times their service is even suppressed. Many transportation agencies do not want to face the costs of having vehicles running when few people will use them, and these times of the day are seen as a burden.

In this context, microtransit services can provide a more effective service because they can adapt their routes and schedules to specific demand points. The operation costs can be reduced by only running the buses for actual pick-ups and drop-offs, thereby saving hundreds of kilometers where the bus runs idle burning unnecessary fuel.

With virtual pick-up and drop-off stops and with the security for the user of knowing at all times where their bus is and when they will be picked up and dropped off, the reliability trust of the service during off-hours of the day increases and demand increments with it.TThis can make the service not only reduce costs but increase benefits due to the generation of a higher number of ride requests.

Moreover, microtransit can contribute to safety and increase the mobility options for many people. At night time, many persons do not feel safe walking through dark and lonely streets. Often the walk to a public transportation stop is too long or the wait for a bus to come is unknown. This produces unsettlement and many people either do not take the trip or suffer anxiety to different degrees. Microtransit provides certainty of when the bus will come and flexibility to drop one off as nearest to their destination, thereby eliminating the necessity of taking excessively long walks at night for people unsettled by it.

3.2.4 Specific services

When a larger group of people share either origin or destination at a given time, an opportunity for microtransit arises. A single vehicle can become a convenient collective transportation semi door-to-door service for many. This is the case for:

- School drop-offs
- Airport drop-offs
- Commuting
- Enternainment and sports events

School drop-offs can benefit from microtransit to deliver children to school, by organizing pre-arranged pick-ups without the need for extensive coordination between the school and parents. Parents would only have to set their preferred pick-up location and routes would be created optimal for all children, with precise pickup times to deliver all at school on time. This is a safe and reliable way for kids to go to school in a direct way, wihtout having to be carried by their parents or use regular fixed public transportation services.

Airport drop-offs is another application that suits perfectly with the nature of microtransit. Nowadays, when arriving to a new city, poeple either get an expensive taxi or use long public transporation trips, that often are inconvenient and long. The taxi option is convenient, but it is expensive and it contributes to low vehicle occupancy and bottleneck congestion problems and entries and exits of cities. Microtransit can deliver the conveniency of taxis, while being a collective mean of transportation, increasing vehicles occupancy and decreasing the number of vehicles on the roads.

Commuting gathers the characteristics for microtransit to deliver a convenient service that goes in line with commuters' prefferences and traffic alleviating priorities of public entities. Microtransit can work for adding additional capacity to busy corridors during commuting hours (MaRS, 2016). While microtransit is not an effective mean for long-distance high-capacity transportation (See Section 2.3.5), it is a fitting alternative to add capacity to collective transportation means in a city when transportation is overloaded. Chariot[3] is a clear example of microtransit being applied for adding additional capacity in commuting corridors.

Entertainment and sports events gather large amounts of people at the same time with the same origin or destination. Transportation services in cities overload and traffic jams and congestion on the roads are frequent. Microtransit can work as an agent to add extra capacity to transit and promote a modal shift from cars to buses. The adaptability and flexibility of on-demand services pose a suitable solution for those who use their vehicle to go to these events.

3.2.5 Private company transportation

Many companies offer transportation services to their employees. Sometimes by providing them private vehicles (especially for top executives) or by creating bus services to carry their employees to work. At the same time, bigger companies with large-scale headquarters have the need of a mobility service inside their operation centers. Same as with school and airport drop-offs, users share destinations (workplace) and schedules (entry time at work), making the context favorable for a microtransit service.

In the case of private commuting services to company employees, enterprises can offer a controlled and user-tailored service to their employees, improving the transporation services they many already offer (with their current fixed-route services).

For company clusters in industrial parks in city outskirts, microtranist could be a combined hired service by different companies in the same cluster to offer collective private transportation to employees in the whole industrial park.

3.3 Challenges of microtransit

This section lays out the challenges that microtransit faces. Although it represents a step forward for transportation in many ways thanks to the use of modern IT technology and the disposition of offering a user-tailored flexible collective transportation service, it poses some issues that should be taken into account.

Microtransit is at risk of not being implemented for the general welfare of citizens. One must not forget that microtransit is just another form of transit in cities, thereby it should serve the good of the majority of people. If one thinks of it from the perspective of how it could cater to their own life experiences, one will lose perspective and assess this mean of transport incorrectly. Often the wealthiest sectors of the population have the most power to push forward initiatives that may only benefit them even though they might think it will serve everyone, this phenomenon is called *elite projection*, and transportation is at risk of falling into this mistake (Walker, 2017). Cities have limited space that large numbers of people share. Therefore, efficiency in transportation and efficient use of capacity is crucial when designing effective means of collective transportation. If microtransit is thought of as a stand-alone service, that does not connect with other forms of transit and that roams all around inside cities it can be counter-productive to society. It can be seen as a more comfortable and expensive alternative

[3]North American transportation services company, founded in 2014.

to public transportation. It can improve customer experience by making it possible for the customer to get a seat reservation, shorter walking distances and better point-to-point flexibility in urban areas. This may lead to many **people shifting from high capacity means of public transport to microtransit**, which would be utterly inefficient. Microtransit would lower average vehicle occupancy and increase the number of vehicles on the roads. On top of that, congestion and traffic jams would increase and air quality decrease. Because of this, it is of paramount to adequately plan the areas of influence of microtransit.

In the busiest urban areas and corridors, microtransit **cannot match the efficiency of high-frequency high transit**. This is straightforward to assess by only looking at numbers. Microtransit is thought of for carrying 10-15 people per vehicles, while articulated buses, for instance, carry more than one hundred people per vehicle. In high-density areas, with high demand for transit, microtransit should not compete with traditional means of fixed-route transport.

A natural trait of microtransit is to adapt to demand and users' requirements by constantly detouring for pick-ups and drop-offs, instead of users walking a distance to adapt to a fixed-route line. Because of this, **microtransit vehicles are constantly meandering and covering longer distances**. If this meandering and detouring do not consequence in a modal shift more cars, it will only mean that the bus is doing more kilometers and increasing CO_2 emissions for the wrong purpose.

Microtransit is making great progress in taking advantage of new technologies to improve their service. Microtransit exploits the fact that users have smartphones that are constantly connected by geolocation services and internet coverage. Virtual bus stops in streets and corners where buses or vans can stop for flexible pick-ups and drop-offs offer a more convenient service to users. With this, the so-called **digital divide** problem arises. There are lower-class segments of the population that cannot afford or simply do not own a smartphone or an internet connectivity plan. Also, some persons cannot use a smartphone or do not know how to use it (i.e. the elderly or disabled). Therefore, there is the risk of leaving out these segments and turning microtransit into an exclusive service. This problem is common to other on-demand ride-sharing modes, as mentioned in Section 2.4.2.

The previously described challenges **put in risk the success of the main goals of transport** in cities (explained in Section 2.1). Equity, a main goal of transport in cities, is not followed when the potential digital divide and the risk of making microtransit an exclusive service leave out many people from having the possibility to enjoy collective transportation. At the same time, induced rides, inefficiency and a modal shift from traditional means of public transport to microtransit can contribute to increased congestion and pollution, which also go against another main goal of transport, sustainability.

3.4 Implementation cases

In the previous chapters and sections, transportation and microtransit have been analyzed from a theoretical and analytical point of view. Explaining the goals, purposes and forms of transport, the impact of new technologies on expanding the array of collective transportation possibilities, and the role that microtransit can play within this context. On-demand collective ride services have been analyzed from a purpose approach, its goals have been laid out, the contexts in which microtransit is most effective have been explained, and lastly, the challenges that it is currently facing to become a more mainstream transportation alternative have been presented.

Microtransit is a niche market in the collective transportation sector in cities. Several companies are experimenting with its application in many ways. Therefore, by analyzing the different approaches that companies are taking, one can further understand this transit method and observe from a more practical perspective what works, what does not and what purposes it is currently serving in the transportation market.

This section explains how microtransit has been implemented or is being implemented by different companies in several locations in the world. Since each case is different from the other, the exposition of the case of each company will serve to explain the implementation strategies that there are today.

First, the **main microtransit solutions on an international scale** will be presented. One must take into account that this form of transportation is deeply influenced by its context, so the models of microtransit for some cities or countries may not work in other countries. Then, some **microtransit and on-demand ride services at a local level** (in Catalonia and Barcelona metropolitan area) will be presented and analyzed.

Each case will be analyzed and the main traits and characteristics of each will be identified. Some of the business ventures presented below are more technologically advanced than others, but all in all, they try to solve the same transportation problems in different parts of the world, by implementing different forms of on-demand ride-sharing.

After having presented several implementation models around microtransit, a table that sums up and compares the major traits of each is shown (Section 3.4.3, on page 44).

3.4.1 Cases worldwide

The following paragraphs explain different enterprises that implement or have implemented microtransit solutions in different cities in the world. Some of them have failed and ceased their activities (for different reasons that will be discussed individually), and some others are in an expansion phase.

They all approach microtransit in different ways: some are more focused on creating completely flexible routes and stops, that dynamically change; others, focus on creating suitable specific routes for users that answer to the specific needs of a larger group of people.

Kutsuplus

It was a Finish on-demand ride-sharing transportation company that operated in direct collaboration with public authorities in the metropolitan area of Helsinki (Finland), founded in 2012 and shot down in 2015. This project can be regarded as the pioneer in fully route-automated microtransit services, and has inspired many initiatives outside Finland.

Figure 3.6: Kutsuplus company logo.

It started as an answer to increasing car rides and congestion problems in the area and as a way to offer flexible and more convenient collective transportation in the outer areas of Helsinki. They offered a door-to-door service for users, to compete in convenience and sustainability with private vehicle usage.

Kutsuplus had a dynamic-routing system, where optimal routes were being created based on live bookings to suit as best as possible all new demands. They had a fleet of 15 vans (9 passenger capacity each), and they gave service to 700-800 passengers a day on a regular basis. 80% of its funding was subsidized and 20% came from ticketing (Shotl, 2016). Salaries accounted for roughly 70% of the cost (Shotl, 2016), whereas in traditional collective transport they account for just over 50% (as said in Section 2.5). This means that other operational costs were reduced compared to fixed-route services. Kutsuplus' price strategy consisted of a fixed usage fee plus a per-kilometer fee depending on the distance of each ride (Rissanen, 2016).

The system registered a steady increase in passenger usage until the total 15-vehicle capacity was saturated. Along with this, passenger surveys showed positive results and customer satisfaction was high (Rissanen, 2016).

Kutsuplus was shut down because funding was cut off by public authorities. It always remained a small-scale project, that was designed to be scalable. Studies in their final report (Rissanen, 2016) show that vehicular efficiency increased by adding vehicular capacity; the number of rides per hour per vehicle increased by adding more vans. At a larger scale, it could have made the system more profitable. Also, more intensive marketing and more synchronized connections with other means of fixed-public transport would have improved the business model.

Chariot

This North American company started in San Francisco in 2014, and has more than 500 employees today (Crunchbase, 2018b); they are in collaboration with Ford Smart Mobility as an investing partner (Chariot, 2018). They have expanded to other cities in the United States, and have now moved to Europe, starting their service in London.

Figure 3.7: Chariot company logo.

Alternatively from what Kutsuplus did, they first crowdsource information about which are the main routes in the city that need extra transportation capacity during peak hours. Once they identify these routes, they create them after a certain number of potential users have signed up and submitted their payment information. When they have enough people willing to pay for a specific route, they launch it. This route is operated by a fleet of Ford vans that cover the routes with a certain frequency. Users, with their phone app, see the location of these vans and choose to reserve a seat in them at a certain point in the route. In short, their main contribution is to create extra transportation capacity for the city in the routes where there is the most demand for transport (a mode of microtransit explained in Section 3.2.4). They do not have flexible routes, they first acquire information, and when they see there is a big enough market for a given route, they launch it.

As a private company, they are trying to make a profitable and sustainable business in the collective transportation sector. Therefore, they are completely market-driven, hence, they might not offer transportation to respond to citizen's underserviced mobility needs and they can be a competitor to other means of public transportation.

Via

Figure 3.8: Via company logo.

Via is a New York based North American company founded in 2012; today it counts with more than 150 employees (Crunchbase, 2018g). It started operating in New York six years ago, and now has expanded to Chicago and Washington DC. Via also offers rides in the nearby airports for New York and Chicago (Via, 2018).

For the users, the way it works is simple. They book a ride with their smartphone, they get picked up on a nearby corner and they share a ride with other users that an optimization and routing algorithm has matched in the same vehicle. Users can track their vehicle at all times using their app interface.

Via has developed an optimization algorithm that matches new requests with available vehicles in less than a second and creates an optimal shared route for each user. They estimate an average waiting time of five minutes.

They are different from Chariot in that routes are completely flexible and do not specifically follow a crowded commuter corridor. Both these companies are market-driven and follow demand, this is, as private companies they have deployed their services in cities and areas where there is the highest demand to optimize their vehicle fleets.

If Via does not work in cooperation with other public transportation services, they are in direct competition with them and there is the risk of users shifting from higher capacity means of transport to Via, and hence there is the risk of increasing congestion in cities where they are operating.

Bridj

Bridj is a North American company founded in 2014. They started in Boston and then they expanded to Washington DC and Kansas City, however, they ceased their operations in the United States in 2017 (Crunchbase, 2018a).

Bridj halted its operations in the US because they failed to close a partnership deal with a car manufacturer. Their service was very capital intensive, and it was financially difficult to maintain the system running at a smaller scale (wbur, 2017); similar to the difficulties that made Kutsuplus close (see the beginning of section 3.4.1). After the shutdown in the US, Bridj was acquired by Transit Systems[4] and the service was re-commenced in Sidney (Australia) in December 2017 (Bridj, 2018).

Figure 3.9: Bridj company logo.

Bridj now offers flexible bus routes that adapt to each user's pick-up and drop-off locations, by taking into account live traffic status and user requirements. Pick-up locations can be at the requested location, or the system may tell you to move no a nearby location (to which they encourage the user to walk, jog or cycle).

As a private company, they are profit driven, and therefore they lunch routes where there is the most demand for it, by crowdsourcing data and analyzing it. However, they also work in cooperation with other public transit means by creating routes that connect with other public transport stations.

LeCab

LeCab is a Paris-based company founded in 2012 (Crunchbase, 2018d) that is present today in 20 different cities and regions in France (LeCab, 2018c). LeCab is an arm of a bigger company named Keolis, a global transportation company, who have partnered up with Via (previously this section has presented this New York-based enterprise). Via is supplying the technology infrastructure, namely, the routing and optimization algorithm to run the service (Tsipori, 2017).

Figure 3.10: LeCab company logo.

LeCab present themselves as a convenient taxi service to get around Paris easily, that one can book through a smartphone app. LeCab uses Via's technology to connect passengers with seats available in vehicles driving in a similar direction (Tsipori, 2017).

Since multiple customers share the same vehicles, they claim to decrease the number of individual car trips in Paris, and hence, reduce CO_2 emissions, air pollution, and traffic congestion. They also want to connect passengers with other means of collective transport by offering cab rides that arrive on time for scheduled train services (LeCab, 2018a).

They also offer an airport connection service with flat rates that take into account the departure and arrival times (and possible delays) to adjust pick-up times conveniently (LeCab, 2018b). This application of microtransit is explained in Section 3.2.4.

[4] Australian-based transportation company.

Transloc

Figure 3.11: TransLoc company logo.

TransLoc is a North American mobility software technology company founded in 2014 (Crunchbase, 2018f), focused on creating advanced computation for simulating and running microtransit problems in cities. In January of 2018 Transloc became part of Ford Smart Mobility (TransLoc, 2018).

TransLoc offers a variety of services, all with the goal of enabling public transit agencies to improve their transportation services by implementing microtransit solutions in urban areas adequate for it. TransLoc provides a microtransit simulator, that, given a certain demand and supply in a specific context, offers potential results of a microtransit implementation. They also offer a system to run a live microtransit solution and pilot programs to ensure a certain solution works.

The application areas where they expect microtransit systems to be implemented are: first and last mile, coverage services, off-peak transportation and increase of transportation capacity. All these applications have been explained in Section 3.2.

Different from the enterprises presented before, TransLoc is just a software provider that agencies can utilize to implement microtransit. In short, TransLoc is a profit-driven company, however, it operates by partnering case by case with transit agencies, so the outcome of their performance is intended to be integrally satisfactory for the cities' mobility service and quality.

3.4.2 Local cases

This section shows the projects that are being carried out in the greater Barcelona metropolitan area. Evidently, there is not as much variety at such a small scope. However, there are some companies and ventures where microtransit or on-demand ride-sharing solutions are being implemented or trialed.

Shotl

Figure 3.12: Shotl company logo.

Shotl is a Sant Cugat-based company founded in 2017 that offers a software package platform to apply on-demand ride services in collaboration with municipalities and transportation agencies (Crunchbase, 2018e). Shotl offers the technology so that municipalities and agencies can apply microtransit solutions in areas where on-demand transport can perform better than traditional fixed-route, and hence, offer a better overall mobility service to citizens.

Shotl is similar to TransLoc in that they offer a software package and management tools so that network operators can benefit from these and offer microtransit solutions using their technology. Shotl provides a routing and optimization algorithm to match user's needs with available vehicles and create live suitable routes for users.

They offer a complete software package that comes in three forms. A passenger app to book rides and see the status of your vehicle. An app for vehicle drivers to follow the route that the algorithm has set. And a management module that consist of a central console that manages the status of vehicles, availabilities and routes (Shotl, 2018).

They work in collaboration with transport agencies, cities and municipalities by carrying out projects with agreements with them and by retrieving users' mobility data and offering them as an input for better mobility plans for the customers who have created this raw data. Shotl is carrying some on-demand ride-sharing solution in the Barcelona metropolitan area:

Can Barata is an outter neighborhood of Sant Cugat that had a very poor connection to the city center and to the commuter rail. The neighborhood was connected to the city center with a fixed-route bus line that needed a stop over in Sant Quirze and that was going to reduce its frequency for insufficient demand. Shotl has partnered up with the operator (Moventis) and the municipality of Sant Cugat to cover the mobility in this area with a microtransit service that connects the neighborhood to a commuter rail stop (Volpelleres) and to a clinic in the city (Bella, 2017). They use 12 passenger capacity Mercedes sprinters and the average waiting time is under 15 minutes. The cost of running the system is roughly over €100,000 and a standard fixed-route line in that area costs around €300,000. This data comes from a conversation with a member of the municipality of Sant Cugat in charge of mobility.

Vallirana is a residential town just out of the Barcelona city area. They have just now started implementing an on-demand ride-sharing system with Shotl, who works in collaboration with the municipality and the transport operator in the area (Soler i Sauret, S.A.). Vallirana is a hilly town, with low population, where an on-demand transportation system can work better than traditional fixed-route bus lines that are too expensive to run in such a place. The service has just started running (July 2018).

El Prat on-demand service

In El Prat, a municipality just at the souther border of Barcelona that contains the Barcelona city airport, launched a pilot on-demand service in 2014 (Rodriguez, 2014). The objective was to diminish the use of private transport in favor of collective means of transport and cycling. On top of the millions of passengers that go to the airport, the area counts with more than 18,000 workers every day (Rodriguez, 2014).

The service has been carried out by El Prat municipality and AMB (the public administration of the metropolitan area of Barcelona).

Two previously fixed-route bus lines were turned into on-demand, to cover a low demand area that needs to have a public transport connection, specially during peak hours in the day.

Public taxi services

There is a number of towns in Catalonia where implementing fixed-route bus lines is not profitable, nor offers a convenient service for those living in these towns. Some municipalities do not have sufficient demand to justify the implementation of a fixed-route bus lines, and some others have an irregular orography (steep hills, dangerous turns or narrow roads) that impeeds the safe circulation of buses.

For these reasons, some towns have decided to implement subsidized taxi services to offer mobility to citizens. In these cases, citizens are provided with a dial-a-ride service, where an operator connect these ride needs with nearby taxis in the area, that operate for this specific purpose. Some municipalities that use these public taxi services are Pineda de Mar, Castellar del Valles, Alella, Sant Cebria de Vallalta, Sant Andreu de Llavaneres and Sant Esteve Sesrovires.

3.4.3 Summary of implementation cases

The table below summarizes the microtranist implementation forms explained in the previous sections.

Company name	**Origin**	**Company status**	**Routing system**	**Offer**	**Objective**
Kutsuplus	Helsinki (Finland)	Closed	Flexible un-predefined routes	Software and vehicle supply	Economically sustainable public service
Chariot	San Francisco (USA)	Active	Crowdsourced predefined routes	Software and vehicle supply	Profit-driven
Via	New York (USA)	Active	Flexible un-predefined routes	Software and vehicle supply	Profit-driven
Bridj	Boston (USA)	Closed in USA and active in Australia	Adaptable semi-defined routes	Software and vehicle supply	Profit-driven
LeCab	Paris (France)	Active	Flexible un-predefined routes	Software and vehicle supply	Profit-driven
TransLoc	Raleigh (USA)	Active	Flexible un-predefined routes	Case simulations, pilot tests and software suply	For profit in collaboration with public objectives
Shotl	Sant Cugat (Spain)	Active	Flexible un-predefined routes	Case simulations, pilot tests and software suply	For profit in collaboration with public objectives

Table 3.2: Summary of microtransit implementations.

3.5 Conclusions

This section summarizes and highlights the produced conclusions, insights and findings regarding microtransit as an alternative to collective transport.

Purposes that microtransit must pursue

- Enhance coverage and accessibility in places with lack of public transportation
- Create a higher point-to-point flexibility service to increase collective transportation quality in certain locations.
- Offer first and last mile connections to boost intermodality and connect more riders with public transportation.
- Enhance ridership in coverage-driven routes to increase the economic viability of such routes.
- Act as a data source for transportation planning, by being able to more accurately identify mobility patterns and demand points.

Recommendable applications for microtransit

- Replacement of underperforming fixed-route bus lines.
- Shuttle and connection services.
- Off-hour travel time service (valley- and night-hours of the day, etc.).
- Specific services (school and airport pick-ups and drop-offs, sports events, etc.).
- Private company transportation services.

Identified challenges of microtransit

- Risk of becoming an exclusive and higher level mean of collective transport that does not meet the needs of larger segments of the population.
- Possibility of inducing a modal shift from public transportation to microtransit, that can increase the number of vehicles on the roads, create more congestion and become environmentally more damaging.
- Possible inability to match transportation efficiency of fixed-route transit by creating poor routes that cover too much distance and create excessive GHG emissions.
- Risk of creating a digital divide between those who know how to use modern smartphones and technology to interact with the microtransit system, and those who do not.

Business implementation cases

- Most advanced optimization and routing algorithms. Some created completely undefined routes (Kutsuplus, Via, LeCab, TransLoc, and Shotl), some offer predefined routes that modify live depending on user requests and traffic status (Bridj) and some crowdsource routes to offer route where is most demand (Chariot).
- Some are completely profit-driven (Chariot, Via, Bridj, LeCab), some are public (Kutsuplus), and some are profit-driven while aligning their objectives with the public mobility needs (TransLoc and Shotl).

Chapter 4

Case study: microtransit solution implementation proposal

The present chapter identifies an adequate geographical scope of analysis, assesses the current situation of public transportation in the identified area and proposes and describes an on-demand microtransit solution. The proposed microtransit service is built upon the theory displayed in the previous Chapters and takes into account the private sector experiences explained before.

The combination of raw theory of transport in cities with an analysis of the use of new technologies and business ventures regarding mobility builds a firm base on top of which a new purpose-driven microtransit solution can be offered in a specifically analyzed geographical area.

Chapter 2 has shown that collective transportation comes in many forms, and its mobility and economic success will depend on the context it is deployed in and the goals it is meaning to achieve. Therefore, before explaining the microtransit solution, a previous assessment of the target goals and the area where it is intended to be implemented will be given.

One can see in Chapter 3 the manifold forms of microtransit from the experience of several enterprises and the situations, contexts, and purposes for which it can be successful. Together with the challenges of microtransit (also explained in Chapter 3), it can serve as a proper compass to design an alternative microtransit solution that does not fall into the mistakes that other solutions have and offers a quality service to citizens.

Therefore, the following sections are laid out in order to give purpose to the system, analyze its context and area of influence, explain each main aspect of the solution and showcase two examples in two different municipalities of what the service should look like at a local-scale.

4.1 Objectives of the proposal

This section proposes a type of microtransit system, always having in mind the purposes of its implementation. The following list explains the goals upon which the system has been designed and proposed:

- Increase coverage services to increase accessibility and social well-being while maximizing ridership, which has a positive environmental impact.

- Reduce the number of car trips generated due to the lack of a better collective transportation system for citizens.
- Act as a collaborative party with other internal and external public transport services, to avoid a modal shift from higher capacity means of transport to microtransit.
- Offer a collective transportation service in those areas where car dependency is highest, and there is a wide margin to reduce traffic, cut on greenhouse gas emissions and save energy.

4.2 Scope of analysis

The initial paragraphs in this chapter address the geographical area of greater Barcelona and the towns and cities nearby to analyze the possibility of implementing a microtransit solution. This area is extensive and heterogeneous. On the one hand, it comprises Barcelona, the second largest city in Spain and the fourth densest city in Europe (Misachi, 2017). On the other hand, there are many small towns outside of Barcelona, in extensive areas of land and very low-density values. People living in these smaller towns add up to large population numbers due to the fact that the social and economic power of Barcelona draws many people into these towns.

Mobility is different depending on the characteristics of each geographical area. In Barcelona city, public transportation is the most used mean of transport, doubling the use of private vehicles inside the city. On the other hand, in the outer towns within the public transport tariff system of Barcelona per every hundred private transport rides, only four rides happen by public transport (ATM, 2016).

As explained in Section 3.1, in the denser areas with large population numbers fixed-route high-capacity public transportation offer very high efficiencies and a great utility. However, traditional means of transport struggle to offer quality mobility services when population density is low and demand is scattered.

Being consistent with the theory exposed in Chapter 3, Barcelona city itself is not an adequate area today to implement microtransit, due to its high density, small area, and large population. High-capacity fixed-route public transportation caters to Barcelona citizens best.

Therefore, **the scope is focused on the conglomeration of towns outside of Barcelona city**. AMTU (Associació de Municipis per la Mobilitat i el Transport Urbà) is an association that works for the improvement of mobility and public transportation infrastructure at a Catalan level. About ninety-nine Catalan municipalities take part in this association. They all have in common that they currently have a service of public transportation (either in-town or inter-urban) and they take part in the association to have a common and strong party that will work in their best interest to improve mobility in all towns. The **ninety-nine municipalities involved in AMTU** will be used in the scope of analysis in the present project.

Since AMTU regards mobility in these towns, they store extensive and ordered information about mobility.

The following figure shows the geographical area of AMTU, which will be used for the project scope.

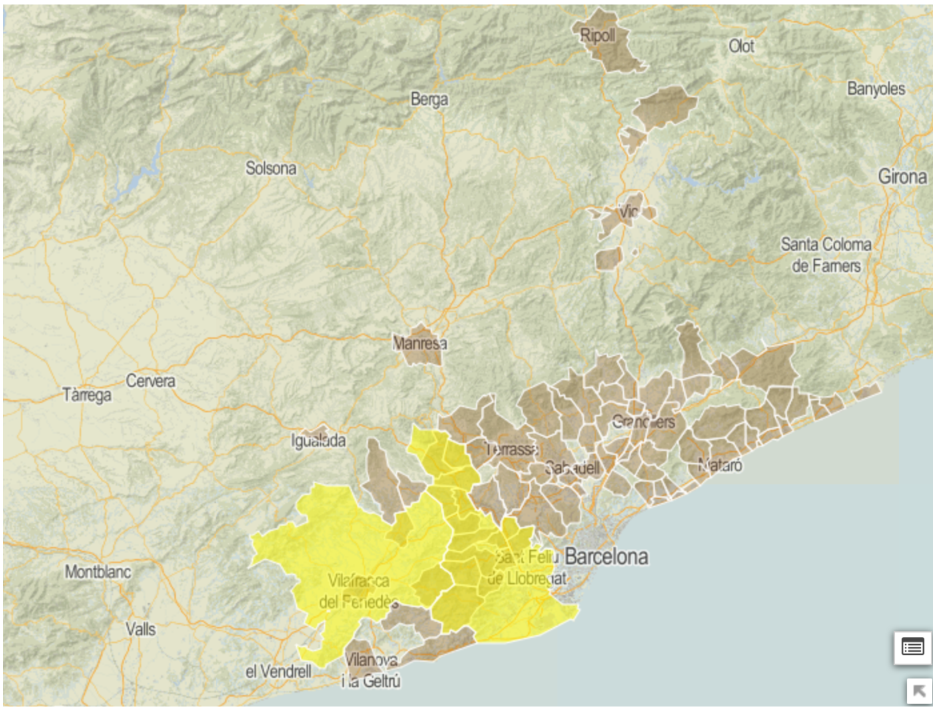

Figure 4.1: Geographical area of the municipalities associated in AMTU.

The dark-brown an yellow areas represent the geographic regions where AMTU municipalities are located. As Figure 4.1 shows, the majority of towns of the scope are part of the greater metropolitan area of Barcelona.

The **land structure** is heterogeneous. An AMTU executive summary from 2011 divides it into three different main kinds: dense urban areas, peri-urban and scattered areas, and rural areas (AMTU, 2011).

i) Dense urban areas

There are large municipalities that count with in-town public transportation services. They are dense and compact, however, they might have neighborhoods and few or poor connections with city centers. Municipalities with a population above thirty-thousand are considered in this group (AMTU, 2011). For instance, Sabadell, Terrasa, Vic or Granollers can be considered part of this group.

On-demand transportation can take place for:

- Off-hour periods.
- Shuttle and connection services.
- Connection of outer neighborhoods with urban nuclei.
- For specific population groups (disabled, under-aged and the elderly).

ii) Peri-urban and scattered areas

Municipalities formed by neighborhoods and scattered suburb areas that are far from central urban nuclei form this group. Up to 80% of the land in these towns is built for family households and suburban areas (AMTU, 2011).

These towns do have public transportation, however, in most cases is part of larger inter-urban services. There is public transport deficit and there is an important dependency for private vehicles for mobility. The terrain is often mountainous, which further hinders public transportation (frequencies are low because distances are long and demand is low). Often, these municipalities are formed in a tree-like structure, with the main road crossing through. Some municipalities that pertain to this group are Corbera de Llobregat, Vallirana, Alella or Vacarisses.

On-demand transportation can take place for:

- Replacement of fixed-route public transportation.
- Shuttle and connection services.
- Off-hour periods.
- Connection of outer neighborhoods with urban nuclei.
- For specific population groups (disabled, under-aged and the elderly).

iii) Rural areas

The smaller towns formed by residential neighborhoods and surrounding agricultural activity are part of this latter group. Farms, cottages, and isolated households can be found in these towns.

Population density is very low and demand for transportation is far and scattered. Larger and middle-sized towns might also have rural areas in their outskirts. Some municipalities with rural areas are Les Franqueses del Vallès, Cardedeu, Sentmenat or Vic (AMTU, 2011).

On-demand transportation can take place for:

- Replacement of fixed-route public transportation.
- Shuttle and connection services.
- Connection of outer neighborhoods with urban nuclei.
- For specific population groups (disabled, under-aged and the elderly).

As previously said, the municipalities that form the scope of this project are different in land characteristics and population size. In the following paragraphs, the ninety-nine municipalities of the project scope will be listed. They have been divided into five groups, depending on their population size.

Group A (population above 100 thousand):

Mataró, Sabadell and Terrasa.

Group B (population between 50 and 100 thousand):

Cerdanyola del Vallès, Granollers, Manresa, Mollet del Vallès, Rubí, Sant Cugat del Vallès, Vilanova i la Geltrú, Lloret de Mar, Sant Pere de Ribes and Olesa de Montserrat.

Group C (population between 20 and 50 thousand):

Barberà del Vallès, Blanes, Castellar del Vallès, El Masnou, Esparreguera, Igualada, Martorell, Molins de Rei, Pineda de Mar, Premià de Mar, Ripollet, Sant Vicenç del Horts, Santa Perpètua de la Mogoda, Sitges, Vic, Vilafranca del Penedès, Canovelles, Arenys de Mar, Piera, Torelló, Cunit, Pallejà and Ripoll.

Group D (population between 10 and 20 thousand):

Abrera, Argentona, Caldes de Montbui, Calella, Canet de Mar, Cardedeu, Castellbisbal, Corbera de Llobregat, La Roca del Vallès, Les Franquesès del Vallès, Lliçà d'Amunt, Malgrat de Mar, Montornès del Vallès, Palau-Solità i Plegamans, Parets del Vallès, Premià de Dalt, Sant Andreu de Llavaneres, Sant Celoni, Sant Quirze del Vallès, Sant Sadurní d'Anoia, Vallirana and Vilassar de Mar.

Group E (population below 10 thousand):

Alella, Bigues i Riells, Cabrera de Mar, Caldes d'Estrac, El Papiol, l'Ametlla del Vallès, Lliçà de Vall, Sant Antoni de Vilamajor, Sant Cebrià de Vallalta, Sant Fost Campsentelles, Sant Vicenç de Montalt, Santa Eulalia de Ronçana, Santa Maria de Palautordera, Sentmenat, Teià, Torrelles de Llobregat, Vacarisses, Valldoreix, Viladecavalls, Vilanova del Vallès, Cervelló, Montmeló, Arenys de Munt, Masquefa, Tona, Sant Esteve de Sesrovires, Begues, Roda de Ter, Dosrius, Sant Pere de Vilamajor, Olivella, Vallgorguina, Gurb, Vallromanes, Calldetenes, Sant Pere de Torelló, Castellví de Rosanes, Olesa de Bonesvalls, Gualba, Sant Iscle de Vallalta and Castellolí.

4.3 Current situation

This section breaks down the major characteristics of collective mobility in the area of analysis. As the previous paragraphs have shown, the area of study is very heterogeneous, where small and scattered municipalities mix with denser urban areas.

First, information about mobility and performance values of public transportation will be shown. Then, further explanations will be given about the preferences of public transportation users that will aid to explain why public transportation perform the way it does in the scope of analysis.

4.3.1 Mobility data

In this section, several figures will be displayed that will help describe the state of public transportation in the scope of analysis.

The performance of public transportation is strictly dependent on the size of an urban area and the population density. As the population of a municipality decreases, there is fewer and more scattered demand for public transportation and the performance of such systems goes down. The following graph shows the number of trips per kilometer done on average depending on the population size.

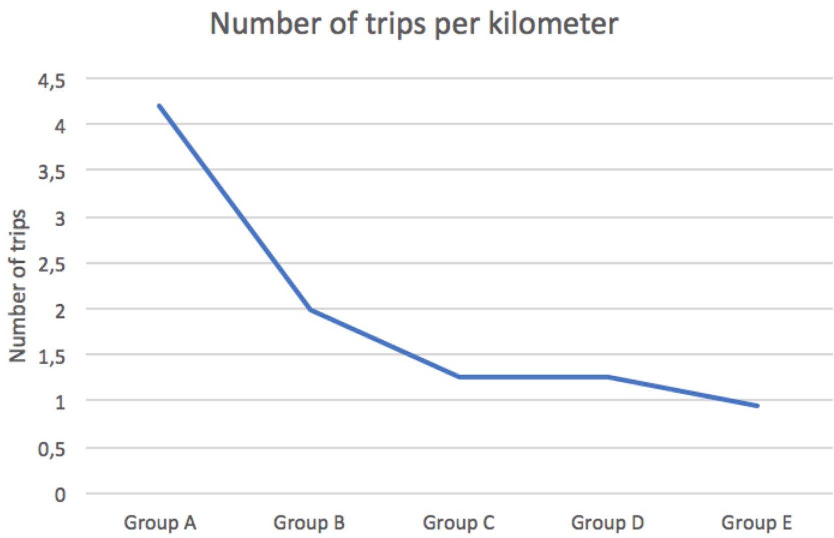

Figure 4.2: Number of trips per kilometer depending on the population group in AMTU. [Data source: (AMTU, 2012)]

Figure 4.2 divides the municipalities of the project scope in the municipality groups explained before. One can see that as the average municipality population decreases the number of trips that public transportation services per every kilometer in operation decreases. This comes as a result of having to cover long distances at low demand levels. Fixed-route public transportation cannot offer an efficient service under these conditions.

Since the number of people that public transport services decrease with population, the economic viability of these services goes down accordingly. If one looks at the economic performance of these systems, one can see that the income from ticketing in public transportation is not able to cover the expenses of deploying and operating large capacity fixed-route and fixed-schedule systems.

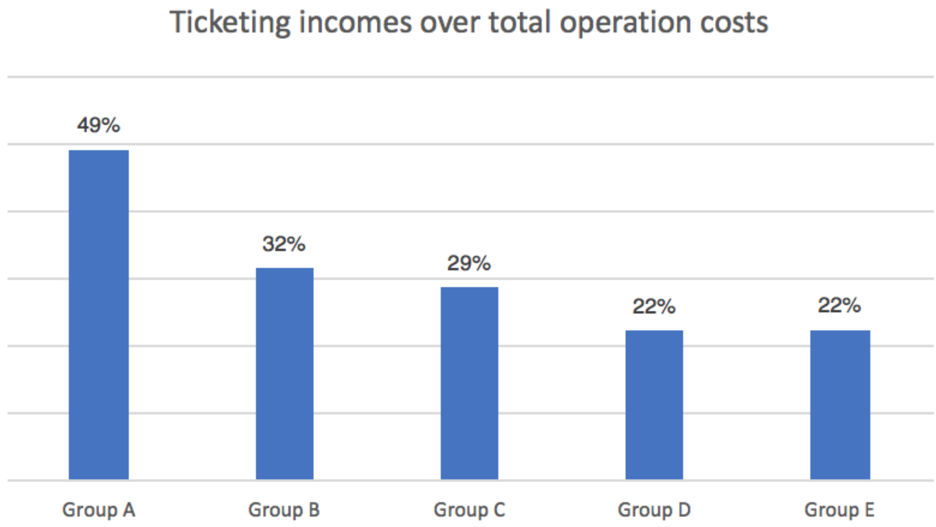

Figure 4.3: Incomes from ticketing of public transportation systems in five population groups. [Data source: (AMTU, 2012)]

The previous figure shows that in the larger municipalities (Mataro, Sabadell and Terrasa), the ticketing income accounts for half of the operating expenses. However, as the population goes down incomes become smaller. For the municipalities in group D and E, ticketing incomes account for only 22%.

When ticketing incomes are so low, to keep a public system running, public investment needs to increase. Subsidies become paramount and the operation of such systems becomes a burden for municipalities. The following figure shows the subsidies needed per trip to keep in operation the public transportation systems in the 5 groups of population of the project scope.

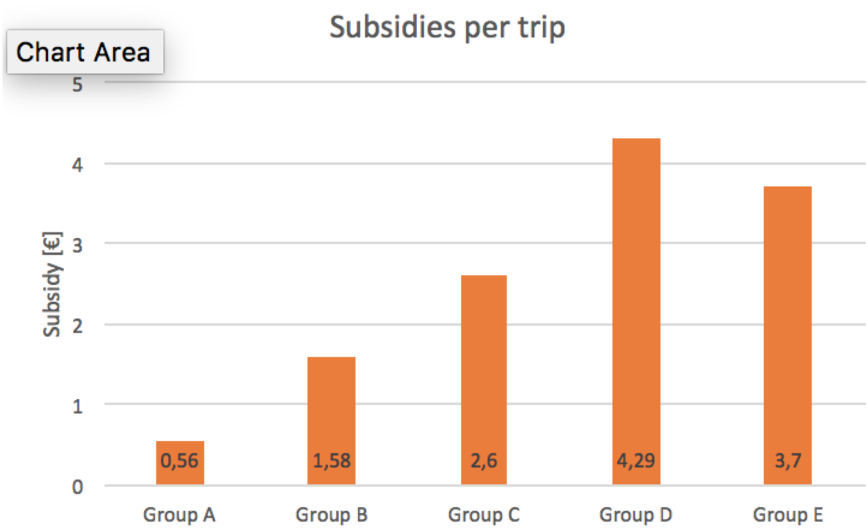

Figure 4.4: Average subsidy values per trip for every population group. [Data source: (AMTU, 2012)]

Group D in Figure 4.4 shows that in those municipalities subsidies are the highest, even higher than in Group E, though average population per municipality in Group E is even smaller. Since municipalities in Group E are so small, it is probable that the average value of subsidization is lower simply because there is much fewer offer for public transportation than in the larger groups. Municipalities in Group A shows a much better performance, per trip subsidization being a bit over half a euro.

Since it is so costly to deploy fixed-route and fixed-schedule public transportation in these areas, the quality of the service given falls accordingly. When long distances need to be covered frequency needs to decrease in order to keep costs under a given budget. In low-density areas, the frequency for buses to come is very low.

The following plot shows the average frequencies depending on the municipality group:

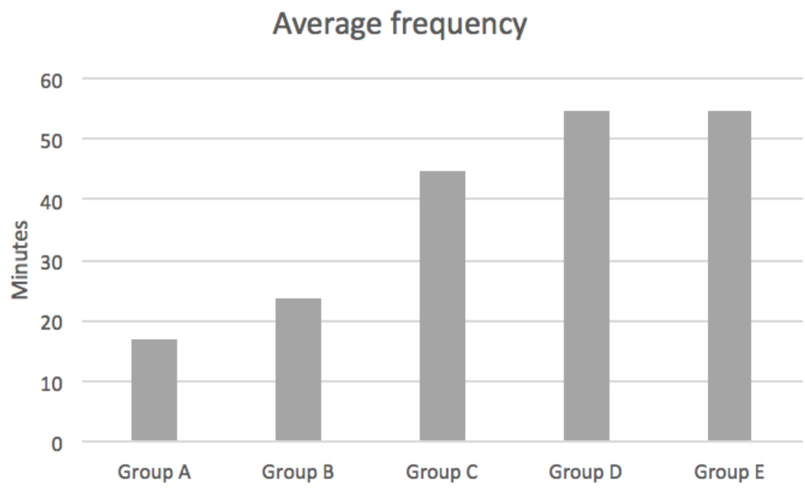

Figure 4.5: Average frequencies per municipality group. [Data source: (AMTU, 2012)]

In Groups C, D and E, frequencies reach above 40 minutes. This hinders incredibly the possibility for public transportation to become a convenient or even viable option. Frequency is what can approximate the sense of freedom that private vehicle drivers have to public transportation users. If one knows that they will not have to wait any longer to start a certain travel, it is more likely that public transportation will become a convenient option. This does not happen on average in any of the five municipality groups of the scope. However, this problem is accentuated in the three smallest.

One must not fall into the mistake of thinking that since public transportation performs worse only in small towns, it is not an important problem to address. Even though the average population per town decreases, the total population of these municipality groups is not lower.

The following pie chart shows the population share per group over the total population of the project scope.

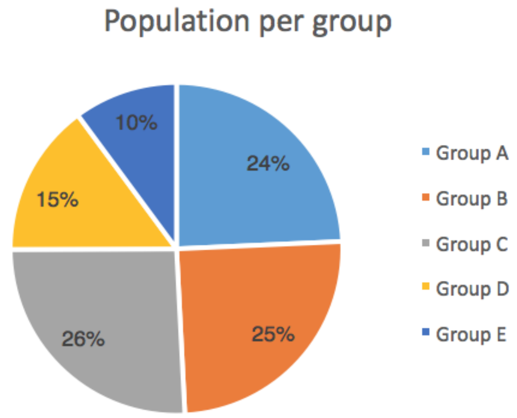

Figure 4.6: Population share of each project scope municipality group.

Figure 4.6 shows that Group C, Group D and Group E account for more than half of the total project scope population. Citizens living in smaller urban areas make as many trips per day on average than those living in large cities, as the following table shows.

Population group	Average trips per person and day
Group A	3.33
Group B	3.34
Group C	3.36
Group D	3,27
Group E	3,27

Table 4.1: Average trips per person and day for each municipality group [Data source: (ATM, 2015)].

Since more than half of the population in the scope of analysis live in Groups C, D and E, the ratio of trips per person is similar in all groups (see table 4.1 and public transportation performs worse in these municipalities, it means that most private vehicle trips happen in these areas.

Therefore, the smaller municipalities present the highest need of having a microtransit solution to solve their car dependency and the inability of public transport to answer to their needs.

4.3.2 User experience

In an extensive survey carried out by AMTU, they analyzed rider behavior reasons for the poor performance of public transportation in many municipalities. 62,8% said that they do not use public transportation because of shortcomings and service quality (AMTU, 2013b). The following list breaks down the main reasons of people who do not usually use public transportation:

- Lack of conveniency - 30.1%
- Bad combination or route - 26%

- Lack of public transportation availability - 21.2%
- Inconvenient schedules - 16%

The previous list shows how the rigidity of fixed-route and fixed-schedule public transportation has hindered its use to a great extent. Bad combinations and inconvenient schedules are consequences of traditional public transport that microtransit can amend.

44% of the people surveyed said that if collective transportation was convenient, they would use it for sure (AMTU, 2013b). At the same time, 87% of the municipalities in AMTU estimate that if on-demand transportation was available, it could give an answer to their current mobility needs (AMTU, 2011).

4.4 Detail of proposal

The proposed service will be explained by tackling each main aspect separately.

4.4.1 Integrated public/private service

The geographical area of study has as epicenter the city of Barcelona, which draws population into many towns around and acts as a mobility generator for citizens living around. As Section 4.3 shows, those municipalities and areas further from Barcelona have the highest car dependency and concentrate in smaller and less dense urban areas.

The municipalities closer to Barcelona, have more public transport options, but they still depend to a high degree on their private vehicles. However, all municipalities in the scope have some sort of public transportation service. In some cases, there are urban fixed public bus routes, and in other cases, the public transportation is part of larger inter-urban fixed routes that stop at several places inside the towns they cross.

For a proper collaboration with the current means of public transport, the system must become part of the main public transportation grid, or at least be able to work within the same terms. Namely, trips taken with the microtransit service proposed should be combinable with other means of public transportation, such as other public buses and trains.

As of today, Barcelona's public transportation agencies are working on a payment system that works with a card for contactless ticketing and payments in order to standardize and integrate all means of public transportation in the whole integrated tariff system (STI) of the Barcelona metropolitan area. This card ticketing and payment system is called T-Mobilitat.

The following image shows the contactless payment card that is prepared to be rolled out in a pilot phase in the fall of 2018 in Barcelona, and it will be expanded to the rest of the STI at the beginning of 2019 (TMB, 2018b).

Figure 4.7: T-mobilitat ticketing and payment contactless card

With such a system in place, the combination of microtransit services in parallel can easily be integrated into the general tariff system of Barcelona.

It is paramount to focus microtransit as a public service and not as an entirely private enterprise. As explained in Section 3.3, where the challenges of microtransit are explained, private companies will work in their own lucrative benefit and the risk of having a transport service in competition with public transportation can be counter-productive for the transportation system of a certain area as a whole.

4.4.2 Multi-platform based service

Modern on-demand services seize the technology already provided mainstream to outsource part of their services and reduce their costs. This is explained in Section 2.5. In short, on-demand transportation companies take advantage of the phone and internet coverage plans that customers are already paying for, as well as the smartphones they use.

Together with the T-Mobilitat card, the proposed microtransit service should allow users to book rides and pay for them using their phones with an internet connection or just by the traditional dial-a-ride system already in place in some municipalities. This latter option is suitable for the elderly or those not so familiarized with IT-technologies.

One of the goals of this transport service (as explained in Section 4.1) is to increase coverage and accessibility in the municipalities in scope. This does not only mean that the service should reach more comprehensibly a certain geographic area, it also means that the service should be available and easy to use for all population segments (such as children, disabled and the elderly).

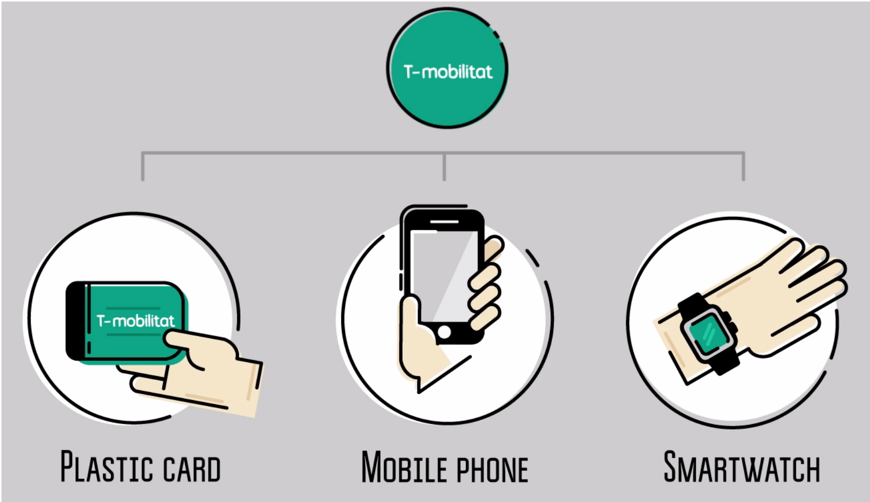

Figure 4.8: Range of integrated options to for bookings and payments with T-mobilitat. [Source: (TMB, 2018b)]

By allowing to make bookings on phone calls and smartphone apps, and by offering payment via the T-mobilitat card and cell phone, the system will be available for all.

4.4.3 Focused on short distance urban travel

Section 4.3.1 shows that in the least dense and scattered areas, collective transportation is the most costly and frequencies are lowest. To avoid this issue at maximum, it is important to define where microtransit services must run.

Looking at the project scope, microtransit vehicles should be deployed inside each municipality's boundaries, without covering any inter-urban travel. If two municipalities are not separated by any inter-urban space (i.e. Barberà del Valles and Sabadell) microtransit vehicles should be able to cross borders.

By concentrating the service within smaller distances the quality of the service will increase. Microtransit will let riders be picked up and delivered anywhere inside their municipalities and since the system's vehicles will always be traveling short distances in town, it is more likely that waiting time will be reduced and the service will become a convenient option.

Focusing microtransit on a local scale, it can overcome the traditional problems of fixed-schedule and fixed-route bus lines.

4.4.4 Multimodal

Since the service aims to run only inside municipalities, it is important to offer a great integration with longer-distance and higher-capacity means of transport. A side consequence of improving transport within town boundaries is that inter-urban travel can directly worry about covering the distance between municipalities, without detouring and wiggling excessively inside towns, which is too time-consuming.

Therefore, microtransit can improve the performance of other inter-urban rail-based and bus-based means of public transportation by bringing scattered demand into central bus and train stations and alleviating the need for public transportation to make meandering and inefficient routes. Figure 3.5 in Section 3.2.2 shows a visual example of the type of multimodality that the microtransit service enables.

Thanks to the integration of the T-Mobilitat card, multimodality can easily be carried out by being able to transfer from on-demand services to traditional systems with the same card on same journeys.

4.4.5 Live and flexible routing algorithm

Since demand is scattered, it does not make sense to have a vehicle go to a place where nobody is waiting to be picked up. This is a misuse of time and money that small municipalities cannot afford (See Section 4.3.1) if they want to have enough money to make a service convenient for potential riders. Therefore, in places where demand cannot be drawn into a fixed route that people will adapt to (as it happens in high-density areas), vehicles need to go where there is someone in need of a ride at the time when this person needs it.

Because of this, it is crucial to have a system that is able to adapt to demand in real-time. This way the efficiency of the system can be boosted, by having vehicles always moving with a purpose, and never for the sake of continuing a random route.

However, this route flexibility can come in two forms: it can follow a predetermined route and leave it any time there is a pick-up or a drop-off, to then come back to the route, or it can be completely free from any predetermined routes and only move upon new requests. In bigger towns, the first option is more adequate because there are sufficient people in those towns to create mobility patterns that the microtransit service can use as a reference. For most of the smaller municipalities, the option of following no predetermined route is more adequate because there are insufficient people to create more solid mobility patterns.

In terms of the algorithm used in the routing process, there are two algorithms that need to be combined into one system:

- In-advance requests: one algorithm that retrieves all the ride bookings requested in advance, and creates planned routes in accordance with the requirements. The algorithm can suggest earlier departures, different pick-up or drop-off points (always at walking distance, which should be established, i.e. 300 meters) so that the routing is optimized.
- Live requests: a second algorithm must work in combination with the first to fit new requests with currently established routes or with the location of near vehicles. Limitations must be set about how long can a current ride be delayed to fit a new one (it could be zero, if a current ride aims to connect with the departure time of another public train or bus), how long is the system willing to make riders walk to fit better into a current route (this can be a choice for the riders to make). Given these limitations and the flexibility of the rider, the system can offer a fast pick-up by adapting the current route or it can tell the rider they must wait longer until the route is freed. Since the area of operation should not be excessively extensive, as explained in Section 4.4.3, waiting time should never be too long, even in the worst case.

There are several private enterprises that have already successfully developed the software that solves live routing and optimization problems continuously to offer direct vehicles amongst the urban thread in an optimal manner. See Section 3.4. Companies like TransLoc and Shotl (presented in Section 3.4) already offer such platforms to public entities (such as municipalities or public transport agencies).

4.4.6 Small-capacity vehicles

Smaller vehicles give the advantage of enabling more flexibility to overcome difficult orography, such as steep slopes and closed turns, as well as being able to go on narrow roads and smaller paths.

On top of this, microtransit is not meant to be carrying large numbers of passengers at the same time, this is why it should be deployed in low population and scattered demand areas, and not in large city centers. Due to the nature of its operation, few people will be riding the vehicle at the same time.

Microbuses and larger vans are the most convenient option for on-demand services. In Section 3.4.2, the pilot project of the Sant Cugat company Shotl is mentioned, where the poorly connected neighborhood is connected with a larger train stop and a hospital. In their case, they use the Mercedes Benz Sprinter van, which can fit a total of 12 seats. For this project, this same van will be proposed, as it covers the explained requirements for deploying a microtransit service, and it is already being used in the private sector.

Figure 4.9: 12-seat capacity Mercedes Benz Sprinter [Source: (Royale, 2018)].

4.5 Showcase examples

Each municipality is different and enjoys its own peculiarities, so it would come to an individual analysis of each town to design a completely proper system for each. However, this task is out of the scope. This project intends to analyze the conditions required for microtransit to become successful and assess what impact it could potentially have at a larger scale (the metropolitan area of Barcelona), given the broad characteristics and mobility behavior in this area.

This section aims to showcase two examples to give a clearer view of why such service could run and how it would work at a more local and detailed scale. The chosen examples try to represent a certain type of municipality that can be relatable to a larger fraction of all municipalities in the scope of the project.

First, a larger municipality, where certain areas or neighborhoods are currently very poorly connected, will be shown. In this case, microtransit has a role of connection and support of other means of collective transport, while increasing accessibility in some urban areas. Multimodality is an important characteristic of on-demand transportation in this application.

Secondly, the microtransit service for a small and very low-density town will be shown, where fixed-route public transport is not solving the mobility of many and car dependency is very high. In this case, microtransit almost works as a stand-alone system by replacing poorly performing fixed-route bus lines.

4.5.1 Connection and support system

To describe how this microtransit service can work as a connection and support system, the municipality of Cerdanyola del Vallès has been chosen, a municipality in the region of Vallès Occidental, just outside of Barcelona city.

Cerdanyola has a population of 57,723 (Idescat, 2018) and is the fourth largest municipality in the scope of analysis. Its surface area is 30,56 km^2 (Idescat, 2018) and its density is 1889 pers./km^2 (amongst the highest in the scope).

The following figure shows a map view of the municipality.

Figure 4.10: Map view of Cerdanyola del Vallès.

Currently, public transportation is formed by commuter trains that come from Barcelona and cross the municipality stopping once or twice, and continue on a larger route; and by 3 urban bus lines and 8 inter-urban bus lines that cross the town at different points and three routes at night.

In the town center, there is good coverage of public transportation, but as one goes further from the center the availability of public transport decreases.

Public transport accounts for 7.9% of all daily trips in Cerdanyola (AMB, 2013) but must of these trips are inter-urban (especially by means of the rail system). If one only looks at the trips inside Cerdanyola del Vallès, public transportation only accounts for 1.8% (AMB, 2013).

The public transportation grid seems to cover enough terrain to be much more successful than it actually is. The following figure shows all the urban bus lines and bus stops painted on top of the map of the municipality.

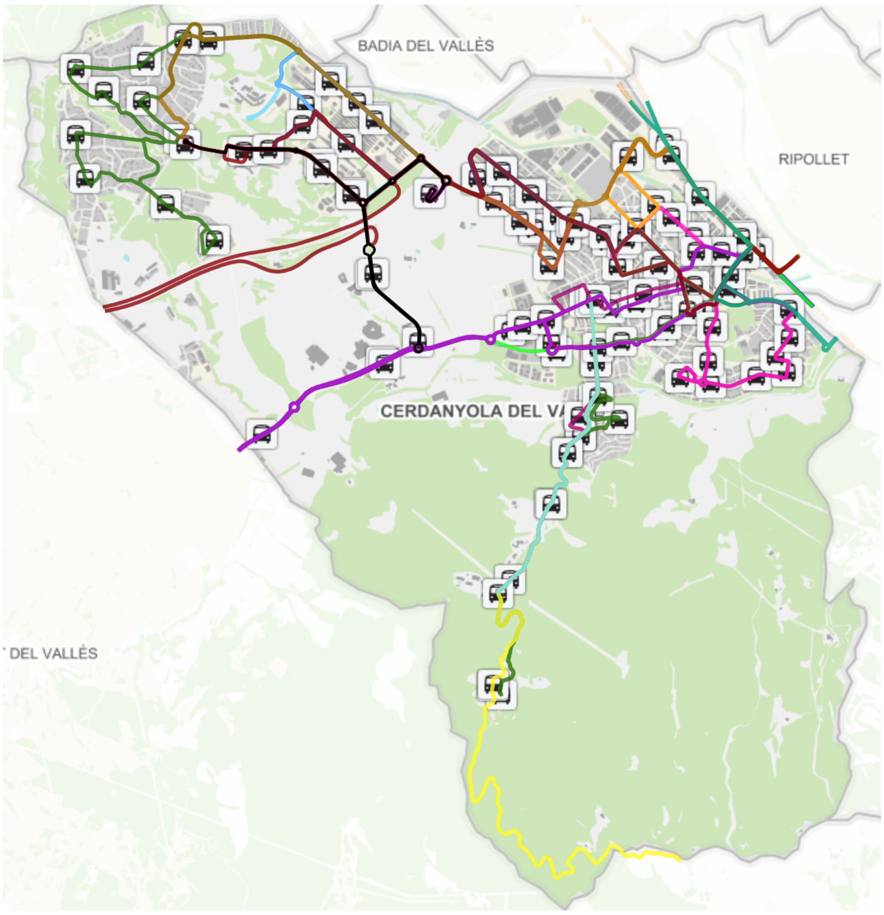

Figure 4.11: Map view of Cerdanyola del Vallès with the urban bus lines and bus stops indicated. [Source: (Cerdanyola, 2018)]

So, the reason for urban public transport to perform so poorly is not on lack of public transportation routes. Then it must be low-frequency values, that hinder the possibility for public transport to become a convenient option, reducing waiting times and giving the possibility for riders to make trips whenever they want.

If one looks at the frequency of the four urban fixed-route bus lines in Cerdanyola, the frequencies are:

- Bus urbà 1: 30 minutes frequency from 6:30 to 22:00.
- Bus urbà 2: only 6 trips per day at 9:30,, 11:30 and 17:30 in one direction and at 10:00, 12:00 and 17:30 in the opposite direction.
- Bus urbà 3: 30 minutes frequency from 6:45 to 20:45.

One can see that frequencies are very low, always above 30 minutes, which clearly supposed a hurdle difficult to overcome. Frequencies are low because these bus routes run practically all day. Therefore, the budget set by the municipality for transportation is not letting Cerdanyola increase frequencies.

To analyze mobility patterns inside the municipality, a report done by AMB breaks down the town into 6 different zones.

Figure 4.12: Cerdanyola del Vallès divided into six different zones. [Source: (AMB, 2013)]

Zones 3, 4 and 5 represent the city center, where distances are shortest and where the majority of the daily trips happen. Zones 1, 2 and 6 correspond to outer neighborhoods and areas of the municipality.

Now, the mobility in these zones will be analyzed, to determine where microtransit flexible routes are most needed. The following figure shows, for trips done in between zones, that share of trips by mode of transport.

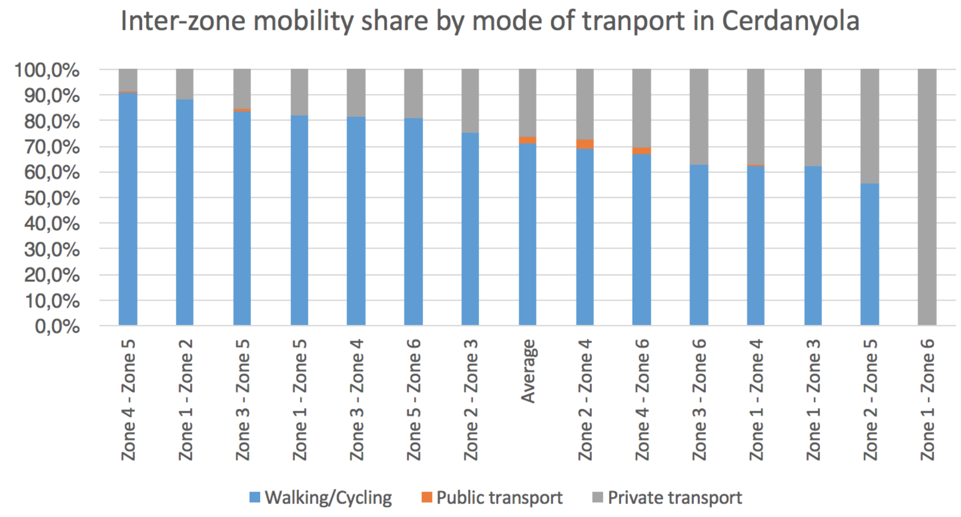

Figure 4.13: Interzone mobility share by mode of transport in Cerdanyola del Vallès. [Source of data: (AMB, 2013)]

Figure 4.13 shows that most trips are done by walking or cycling, and practically all the rest are done by private vehicles. For trips in between the central zones, the private vehicle share is the lowest, but in zones 1, 2 and 6 the private vehicle share increases. Therefore, these are the areas where microtransit must focus.

- *Focus areas for microtransit service: Zone 1, Zone 2 and Zone 6.*

If one looks at mobility inside each zone, this is the share by means of transport:

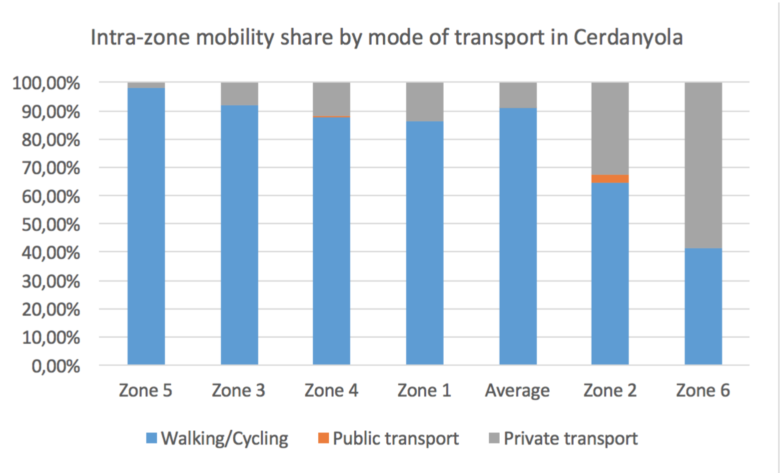

Figure 4.14: Intrazone mobility share by mode of transport in Cerdanyola del Vallès. [Source of data: (AMB, 2013)]

In this case, Zones 1, 2 and 6 are also the most private vehicle dependent.

Decision-making process of the algorithm for multimodal connection

Now, a simple example of how should the algorithm constantly work will be explained. The following figure helps visualize the decision-making process of the algorithm at the basic level.

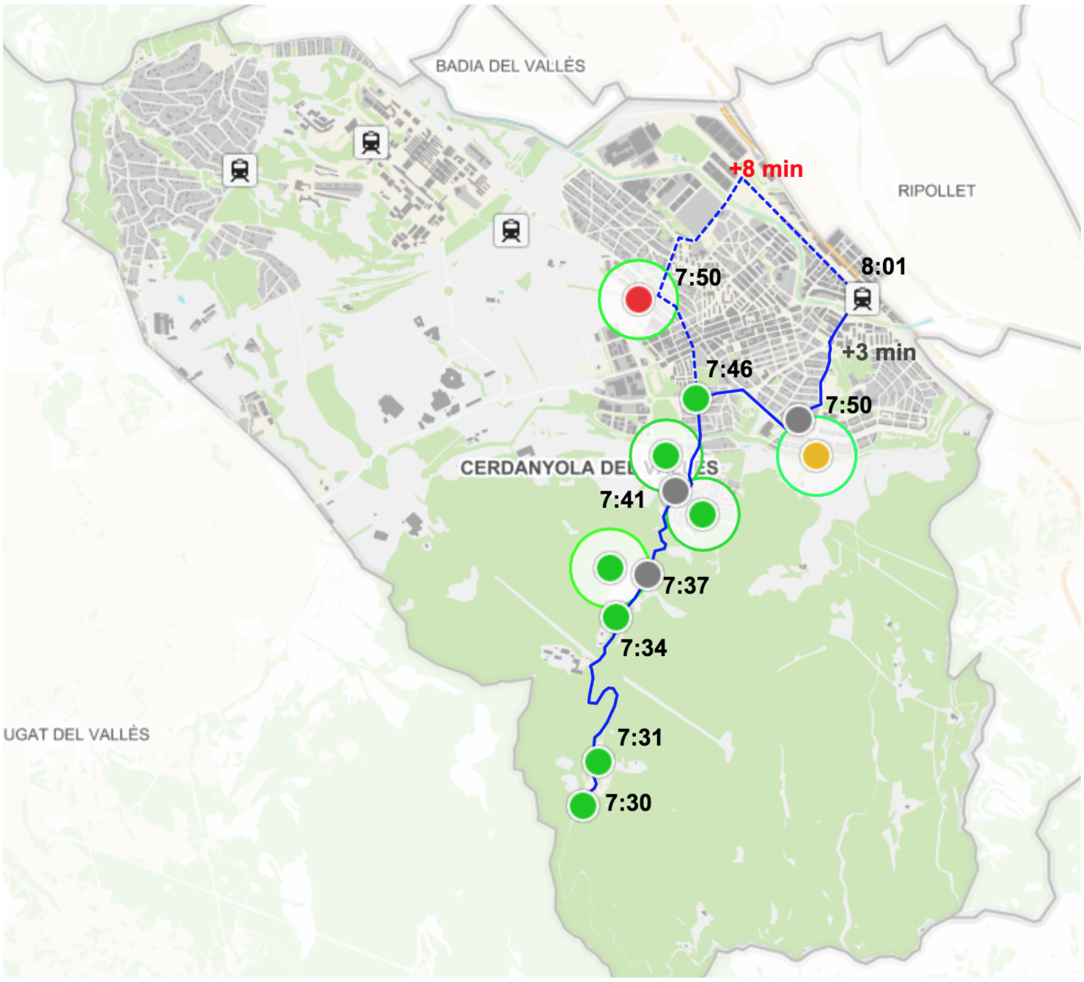

Figure 4.15: Example of the process of creation of a live route in Cerdanyola del Vallès.

The green dots are transportation requests that have been pre-ordered (i.e. one day in advance), the yellow dot is a live request that has been accepted into a running route, the red dot is a live request that has not been accepted into a running route, and the grey dots are pick-up locations of accepted requests.

In the example of Figure 4.15 the microtransit service has created a route that takes people from Zone 2 and the inner city neighborhoods into the train station to catch a commuter train that leaves at 8:01. In this case, several transportation requests have been received to catch this specific train and a route has been created to suit all requests. Then, the pick-up time for each request has been established. Of course, the requests geographically closest to the train station have a pick-up time closer to the departure time of the train.

While the route is running, the algorithm needs to handle different live requests. In the case of the yellow dot, the algorithm has calculated that the incurred delay of servicing that request does not disturb the arrival time requirements of the other riders. In this case, the increased delay is 3 minutes, which is not a problem because the algorithm had scheduled pick-ups with enough time margin.

The red dot corresponds to a live request that the algorithm has not fit in the running route, because the increased delay would exceed the arrival time scheduled from all the other riders. In this case, the delay would be of 8 minutes, which is too long for reliably guaranteeing the rest of the riders an on-time arrival.

Figure 4.15 also shows light green circles around some requests that represent the walkable distance of each rider (which in this case was deemed to be 300 meters). The algorithm has calculated the walkable distance of each and told some riders to walk to a certain pick-up point within their walking distance.

In some cases, when two pick-up requests are close enough, the circle created by their walkable distance can intersect, and a common pick up point can be created. Figure 4.15 has a common pick-up point, but to see it more clearly, the following example shows a common pick-up point for two nearby points.

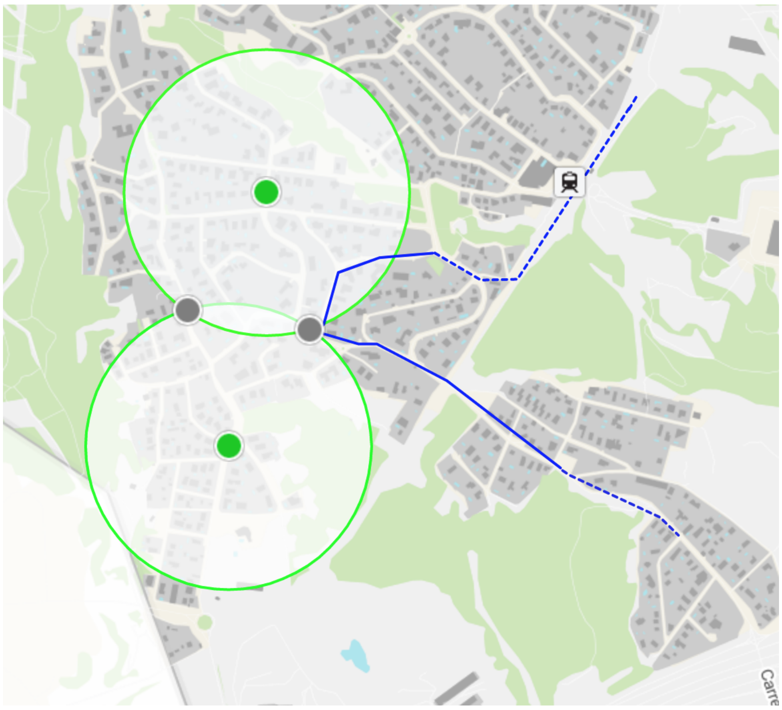

Figure 4.16: The walkable distance of two pick-up points intersected into one common point.

Figure 4.16 shows how the algorithm can optimize a route by creating a common pick-up location between several requests.

Following the creation process of the explained example route, different microtransit vans can be constantly creating new routes in the other heavily car-dependent areas of Cerdanyola del Vallès, allowing quality mobility to people with and without the option of driving.

4.5.2 Stand-alone system

The municipality Corbera de Llobregat will be used to describe what would be a stand-alone system that should offer mobility to the entire municipality (without choosing specific areas). Though tagged as stand-alone, microtransit in this type of smaller towns can also connect with other forms of inter-urban transportation. However, for the purposes of this section, the stand-alone route creation process will be analyzed.

Corbera de Llobregat is a municipality with 14,439 inhabitants, in the scope of the project it is grouped in Group D (the second smallest in average population) and a surface area of 18,41 km^2 (Idescat, 2018), which makes a density of 748 persons/km^2. Currently, nearly 50,000 trips are made on a daily basis (AMB, 2018).

Figure 4.17 shows a map representation of the municipality.

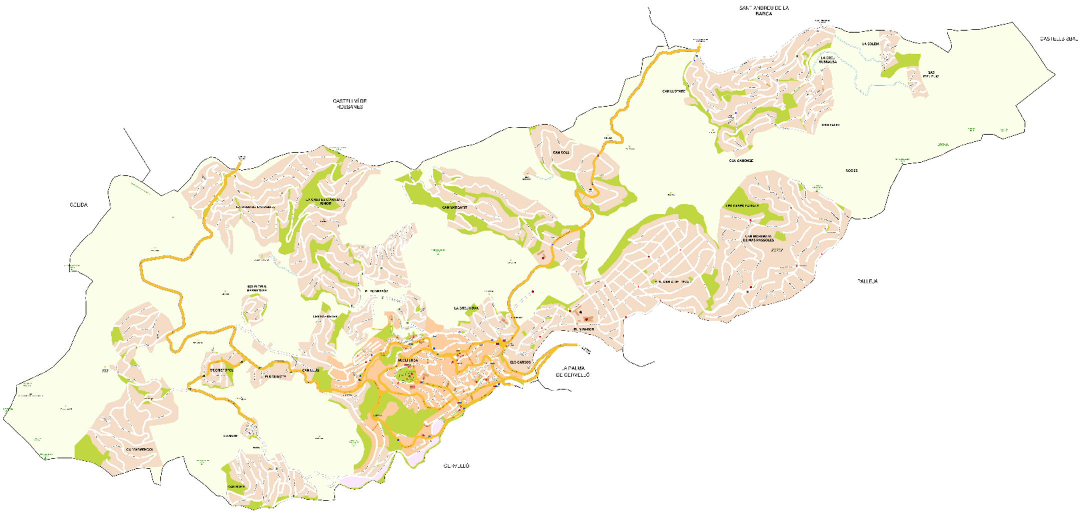

Figure 4.17: Map view of Corbera de Llobregat.

Figure 4.17 shows the geographical formation of Corbera de Llobregat. It is separated in diverse urban nuclei and a central nucleus in the southern part of the municipality. The population is low and is very spread out, which hinders the operation of fixed-route public transportation.

Nowadays, public transportation is formed by four different fixed-route urban bus lines 4 that connect the population nuclei with the center of the municipality and other 4 inter-urban nature (AMB, 2018).

The following figure, extracted from a mobility analysis carried out by AMB; shows the coverage area of the urban bus lines in Corbera de Llobregat.

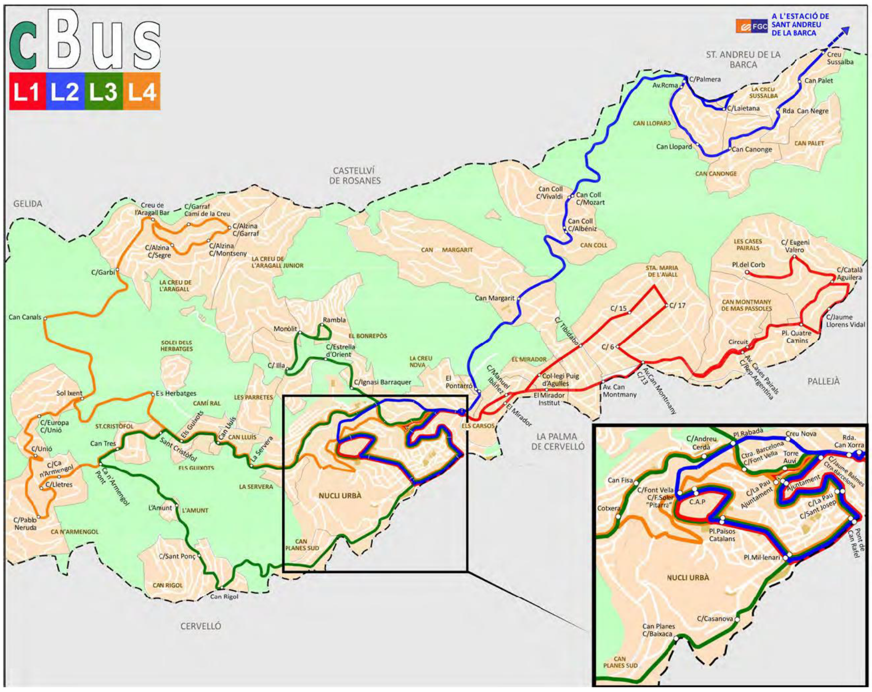

Figure 4.18: Urban bus lines on the map of Corbera de Llobregat.

Similar to the case of Cerdanyola del Vallès, it appears that the urban bus routes cover properly all the urban nuclei of the municipality and connect each other well. Although coverage seems proper, this does not relate to the public transportation usage numbers in the municipality. The modal share stands as following: 72.2% private vehicles, 19,70% walking, and cycling and 8.10% public transportation (AMB, 2018).

Such a low number of public transportation is a consequence of low-frequency values. The following list shows the frequencies of the 4 urban lines (Autocorb, 2018) that are shown on the map in Figure 4.18.

- L1 - Cases Pairals: runs from 7:15 to 20:40 at an average frequency of 1h and 55 min.
- L2 - Sant Andreu: runs from 6:30 to 20.30 at an average frequency of 1h and 4 min.
- L3 - El Bonrepòs - L'Amunt: runs 4 times a day between 6:20 and 20:00.
- L4 - La Creu de l'Aragall: runs from 6:30 to 19.05 at an average frequency of 1h and 45 min.

Such incredibly low frequencies have an adverse effect on the convenience of public transport in Corbera de Llobregat. Therefore, such transport is the least used in the municipality.

Now, mobility inside the municipality will be analyzed, the following figure is a view of Corbera that divides it into two main zones. This map has been elaborated by AMB for a report that assesses the mobility of the town.

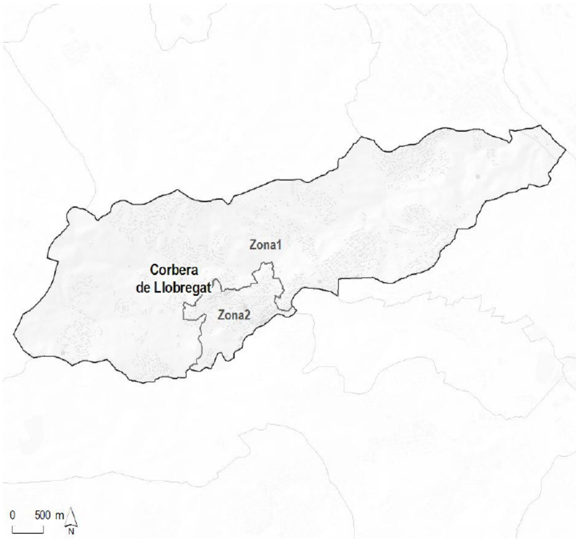

Figure 4.19: Corbera del Llobregat divided into two different zones. [Source: (AMB, 2018)]

Zone 2 represents the town center and Zone 1 englobes the several population nuclei of Corbera de Llobregat. Daily trips in both zones are rather even, 47.5% happen in Zone 2 and the remaining 52.5% take place in Zone 1, out of the total 50,000 trips that take place per day.

Mobility contained in each separate area is car-dependent, especially in Zone 1, where distances are longer. The following plot shows the distribution by mode of transport of trips inside of each zone.

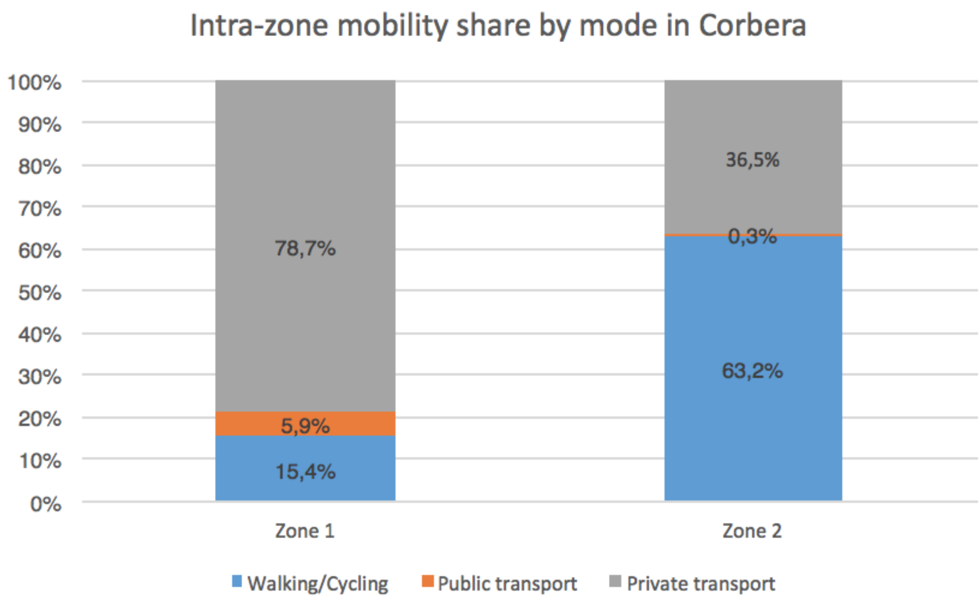

Figure 4.20: Intra-zone mobility share by mode of transport in Corbera de Llobregat. [Source of data: (AMB, 2018)]

Since Zone 2 is contained in such a small area, most trips are done on foot or bicycle. In Zone 1, one can see nearly 80% of all mobility is done by private vehicle, and only 6% of traveling is done by public transportation. In Zone 2 public transport does not even represent 1 percent of the total modal share. Small distances and low frequencies of public transport make this mode inconvenient.

When it comes to traveling in between zones inside Corbera de Llobregat private vehicles take the highest percentage of the share. The following pie chart represents inter-zone mobility in Corbera de Llobregat.

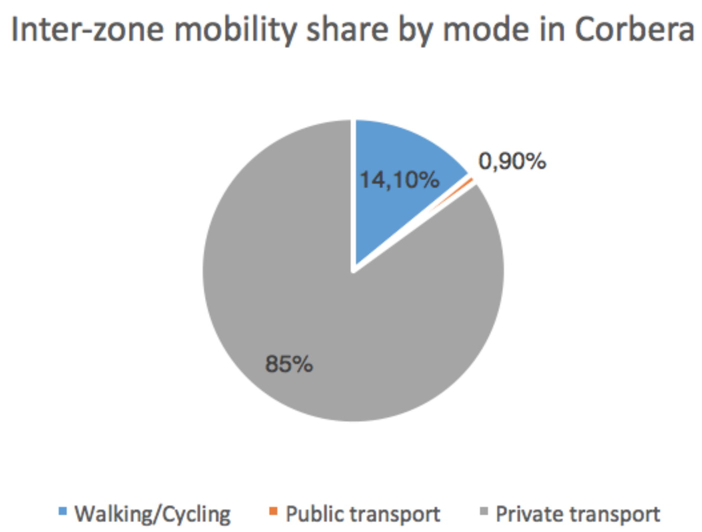

Figure 4.21: Inter-zone mobility share by mode of transport in Corbera de Llobregat. [Source of data: (AMB, 2018)]

85% of all trips are done by private vehicles and not even 1% of the trips are covered by public transportation. Looking at both intra- and inter-zone mobility modal shares, one can determine that entire urban mobility in Corbera is strongly based on private vehicle driving and that the current public transport is not effective.

In this scenario, microtransit has the opportunity to set a system to increase the share of collective transportation by enhancing the quality of public transport.

Public transportation systems work under budgets, which in many cases are tight. When this happens, sometimes high-capacity fixed-route lines do not run for the whole day, due to inability to cover the operating costs of the system because of the low demand and leave certain areas of towns inaccessible during some hours of the day. This is seen in Corbera de Llobregat, where Line 3 (El Bonrepòs - L'Amunt) only runs four times a day – twice in the morning and twice in the afternoon – and leaves the rest of the time no public transportation option for those dwellings and locations dependent of that bus line.

Under these conditions, microtransit offers an added advantage that fixed-route bus lines can never offer. Since the on-demand vehicles do not cover any specific route, they can essentially offer coverage to demand anywhere inside municipalities. When working under a budget, during low demand periods (off-hours and valley-hours) the number of vehicles can be reduced while the coverage area stays intact, because although there will be fewer vehicles, they will still cover the same complete area. Of course, the quality of the service will decrease, as waiting times will increase. Fixed-route lines can never offer such flexibility.

Decision-making process of the algorithm for stand-alone systems

In the Corbera de Llobregat type of municipalities (low population densities and scattered demand), the microtransit service must offer coverage to all parts of town. Microtransit vehicles must travel all around arranging pick-ups and drop-offs and coordinating trips amongst each other to shorten operation distances of each vehicle. This means that two vehicles that will cross and then follow a similar path can interchange passengers in order not to create redundancy amongst vehicles.

Such an example is shown in the figure below, where several flexible routes are being created with in-advance ride requests and live bookings, and two routes interchange passengers at a certain location to decrease running distances and increase frequencies and service quality.

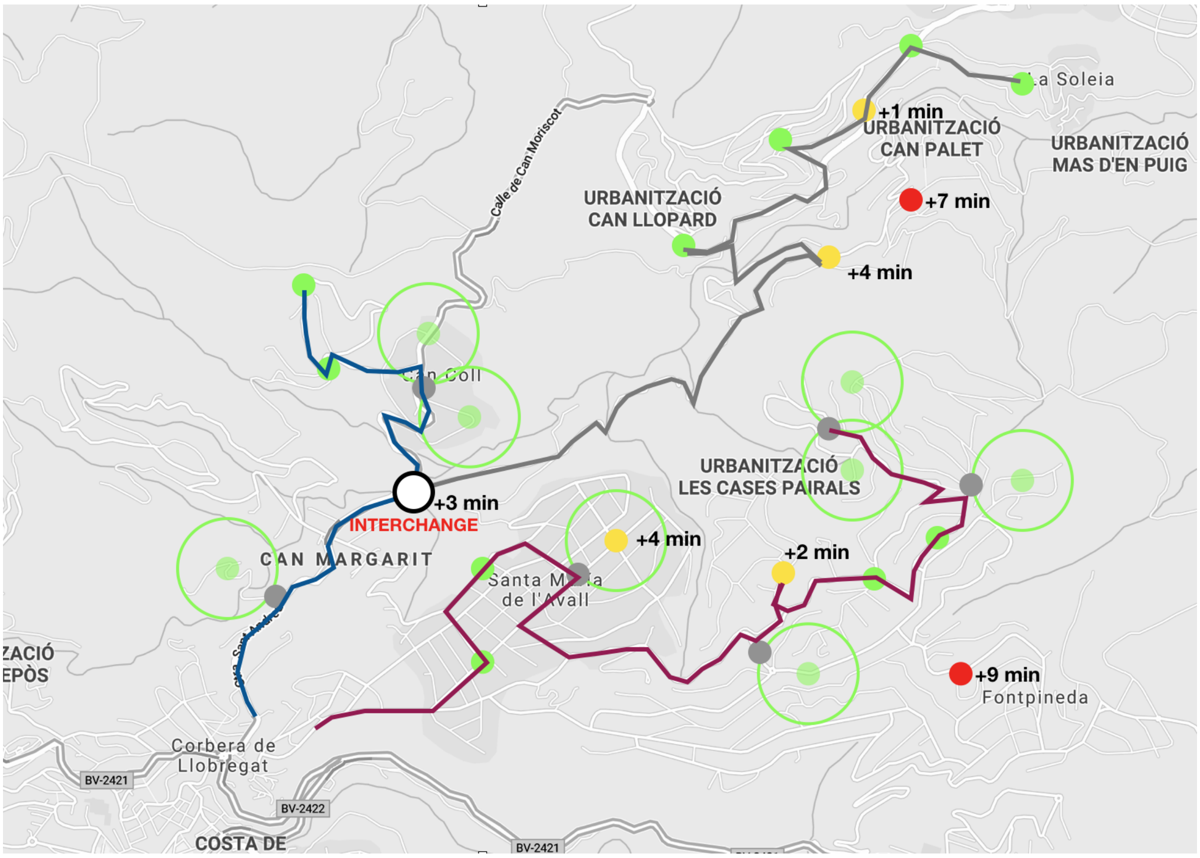

Figure 4.22: Example of the decision making process when creating several stand-alone routes in Corbera de Llobregat.

Following the same process as in the creation of a connection route (Figure 4.15), the system retrieves in-advance pick-up requests (green spots) and creates routes according to them. In some cases, when the algorithm deems adequate, some riders are asked to walk a short walkable distance (green circles around pick-up request locations) to optimize the route for shorter waiting times and distances.

While in operation, live requests (yellow spots) are retrieved, the algorithm estimates the delay in the route for each and decides whether to add new pickups or not. In these cases, both vehicle occupancies and delay times are taken into account). Differently from the connection routes, there is a more flexible margin for admitting live requests, which will be more common than in connection routes.

However, some new live requests cannot be fit into running routes (red spots), when this happens, users will have to wait until the vehicle loops back (the microtransit system will communicate a scheduled pick-up time) or find an alternative mode of transport.

When the algorithm deems it optimal, the passengers in a certain vehicle can be dropped off at an "interchange" stop, where they will be briefly picked up by a different vehicle that will cover the rest of the journey. This is done to minimize distances of running routes so that the vehicles can loop back more frequently to their coverage areas and continue with new pick-ups. This strategy aims to eliminate redundancies between routes and increase the transportation efficiency of the service overall.

4.6 Conclusions

This sections concludes and sums up the main characteristics of the microtransit service proposal, and emphasizes the criteria created and followed to make the decisions that have shaped the system.

Mobility data characteristics of the scope of analysis

- Classified into 5 population groups by average municipality size
- Fixed-route public transportation performs worse as the average municipality size is smaller (see Figure 4.2).
- As the average size per town becomes smaller, the economic viability of fixed-route public transport is more difficult and is more reliant on subsidization (see Figure 4.3 and 4.4).
- The main reasons for not using public transportation in the scope of analysis are: lack of convenience, bad routes or combinations, lack of availability and inconvenient schedules.

Main characteristics for a successful microtransit service

- Integrated with other means of public transport
- Multi-platform based service
- Focused on short-distance urban travel

- Multimodal
- Live and flexible routing algorithm
- Small-capacity vehicles

Microtransit in connection services

- It is important to identify the areas and neighborhoods with lack of availability of public transport, and high car dependency.
- Decision-making process of the algorithm (see Figure 4.15):

  In-advance bookings are used to create connection routes.

  If the route connects with the departure of another mean of transport, adjust schedules to match departure times.

  Live bookings: can be accepted or not, depending on the additional delay time they will suppose.

  The route is optimized by creating virtual stops for requests within a defined walking distance of each. If several requests are at the same walking distance, a common pick-up virtual stop is arranged (see Figure 4.16).

Microtransit in stand-alone systems

- Such systems should work in the least populated areas, with general lack of availability of public transport.
- The routes that the algorithm creates must coordinate amongst each other to shorten the operation distance of each and avoid redundancies (see Figure 4.22).
- It can offer flexibility in tight budget situations by decreasing the number of vehicles in operation while still offering the same coverage service.

Chapter 5

Data analysis and discussion

The **integration of microtransit services** for the ninety-nine municipalities of the scope of analysis explained in Chapter 4 would result in a **downwards shift in energy consumption, traffic, and Greenhouse Gas emissions** in the analyzed area.

The implementation of such microtransit services would also result in other social impacts such as higher coverage and accessibility to public transportation for citizens living outside of main municipality centers and other high-capacity transportation services. However, this chapter specifically looks into the potential environmental impacts of the deployment.

The scope of analysis is very heterogeneous, therefore the adoption rate and success of such a new service would be different depending on the characteristics of each town. Each municipality has a different typology with regards to population, geographic location, type of terrain and urban thread structure.

This chapter proposes a methodology to assess the potential impacts of deploying an alternative transportation system that intends to change the mobility status quo of a certain region of analysis and takes into account the specific traits of each municipality types to assess the potential in the entire system. Then, the proposed methodology is put into practice for the case study of this report, and the outcomes are presented and discussed.

First, the general methodology will be proposed, and then it will be explained for the particular purposes of the case study microtransit proposal of Chapter 4. Here, information about the data retrieval process and particular steps of the methodology that specifically regard to the case study of the present report will be explained.

Then, the results of carrying out the methodology will be presented, where the main outcomes of the deployment of the microtransit service in the scope of analysis in a 5-year period will be shown.

Lastly, the main results and findings will be discussed in order to have a deeper interpretation of the outcomes of the previous section. This section will provide relevant insights to better understand the reasons for the obtained outcomes and their significance.

5.1 Methodology

This section presents the methodology to assess the traffic and environmental impacts of deploying a new transportation service in a certain area, which is divided into three phases:

- **Baseline**: all the necessary information is retrieved and the present state of the scope of analysis in terms of vehicles trips, total travel distances, and Greenhouse Gas emissions is determined.
- **Projected situation with new transportation service**: the progressive change of the present state of traffic and GHG emissions resulting from the implementation of the new transportation service is projected and determined.
- **Determination of the difference between the baseline and projected situations**: the difference between the traffic and GHG emission situations of the baseline and the projection will offer the potential environmental impact of the new transportation service.

Each phase will be presented with a flow chart, and the paragraphs below each will explain more in-depth some the main steps with regards to the case study.

5.1.1 Baseline

The following flow-diagram shows the steps for the calculation of the baseline.

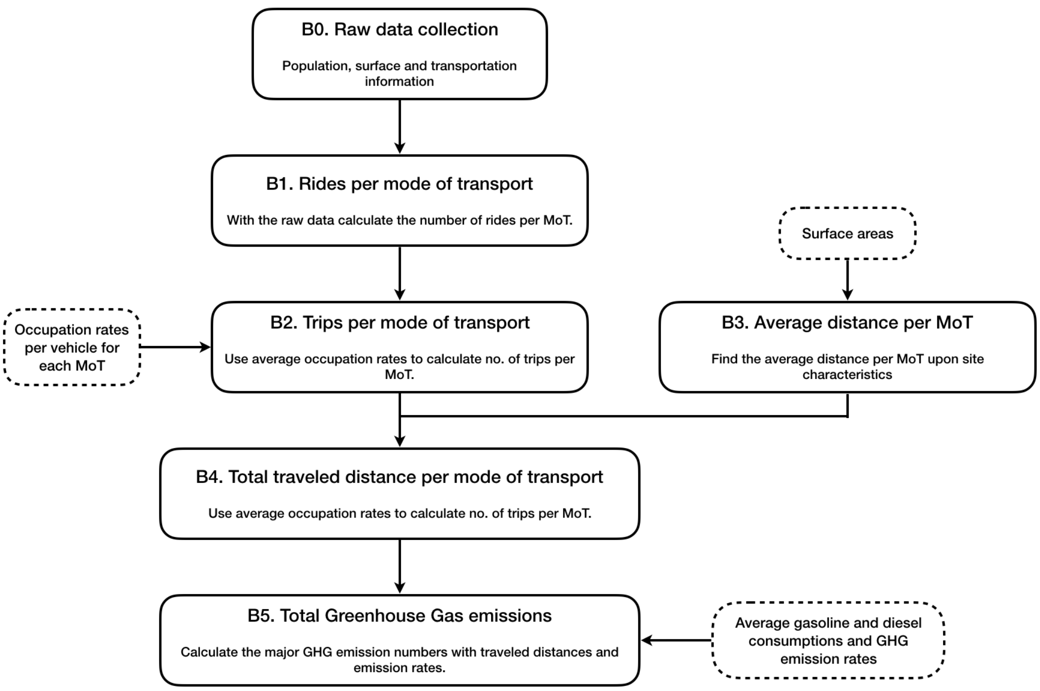

Figure 5.1: First phase of the methodology, calculation of the baseline.

Steps B0 and B1

In the step B0, all the raw data needs to be collected and processed, so that in B1 the rides per mode of transport in the scope of analysis are identifiable. In the case of the present project, this step has been laborious. Since transportation in the metropolitan region of Barcelona is not accurately stored in any database. Since there are different payment systems for many municipalities and ticketing is not digitalized (up to today all public transportation ticketing is issued in paper tickets), there is no common information source. For this phase of the project, I had a meeting with employees of ATM (Autoritat del Transport Metropolità) to find a way to acquire all the information individually. Namely, try to retrieve usage data of each bus or train line in operation, and then add all the information up. Although the information is in their possession, one needs to ask for the information officially and on paper (a process that lasts over a month), and furthermore, I was only able to retrieve such information for a handful of bus lines.

Therefore, the strategy had to be different. I looked at the macro numbers of motorized private trips, non-motorized trips, and public transportation trips and then localized this information to each of the 99 municipalities of the scope.

The following figure features a bar-plot that represents the number of private, public and non-motorized rides per region (comarca).

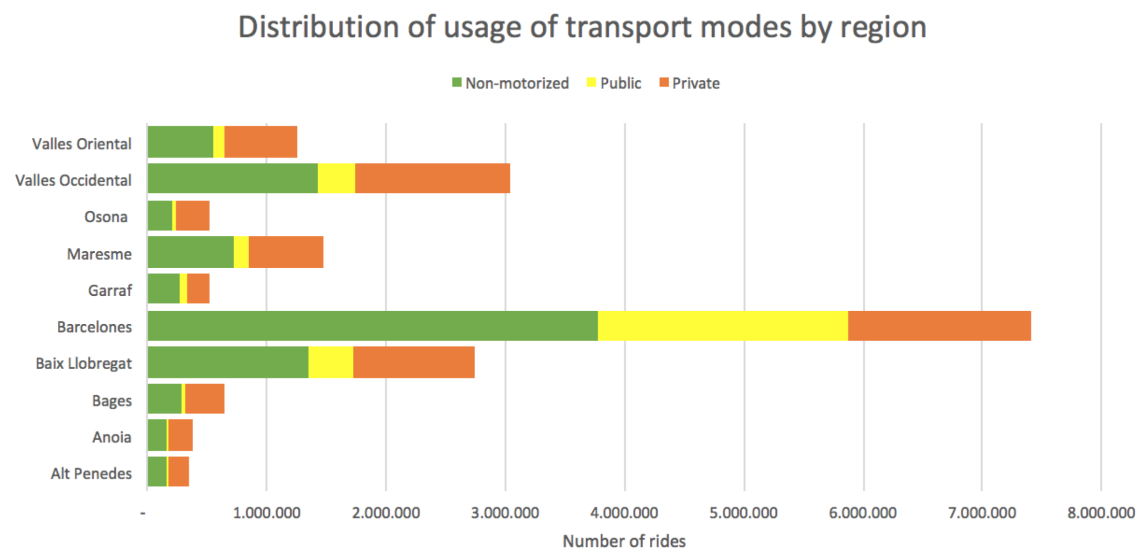

Figure 5.2: Distribution of usage transport modes by region. [Data source: (ATM, 2015)]

With transport mode usage patterns and numbers per region, the population fraction of each municipality in the scope with their respective region with used to localize the number of rides by mode of transport for each municipality.

Step B2

To calculate how much traffic is on the road (step B2), the average private vehicle occupancy rate for transportation in Catalunya was used. For the case study, the number of private cars on the road are of special interest because the microtransit service intends to push a modal shift from private vehicles to microtransit. The executive summary of mobility done by AMTU presents an average occupancy number of 1.83 (AMTU, 2013a).

$$\textit{Average vehicle occupancy in the scope of analysis} = 1.83 \quad \textit{pers./veh.}$$

With the average occupancy rates and the number of rides per mode of transport determined in step B1, the number of trips per mode of transport is calculated:

$$\text{Number of trips per mode of transport} = \frac{\text{Number of rides per MoT}}{\text{Average vehicle occupancy rate}} \tag{5.1}$$

Step B3

To calculate the average distance per trip for each MoT (Mode of Transport) the surface area of each municipality has been considered. An iteration process has been carried out to find a formula related to the surface area of each town so that the average distance per trip of all towns of each MoT coincides with average numbers for the metropolitan area of Barcelona. For this purposes of this project, the average urban trip distance for private vehicles has been calculated, which is the mode of transport that the microtransit intends to get riders from.

In a yearly report that ATM published called ”Observatori de la Mobilitat”, in the revision in December of 2015 they say that, on average, the mean intra-urban distance for urban trips is 2.3 km. Taking this into account, an iteration process has been followed to relate the surface of each town (as if it was round) with the average distance of all 99 towns.

By carrying out this process, the formula that, for this specific project scope determines the average distance per urban trip on a private vehicle is:

$$\text{Average private vehicle urban trip distance} = 0.95 \cdot R = 0.95 \cdot \sqrt{\frac{S}{\pi}} \tag{5.2}$$

where S is the surface area of each municipality.

Step B4

The total traveled distance for each mode of transport is calculated by:

$$\text{Total traveled distance} = \text{Total number of trips} \cdot \text{Average distance per urban trip}$$

Step B5

To calculate the total Greenhouse Gas emissions, in this project, CO_2 emission rates for private vehicles have been taken into account. Internal combustion engine vehicles today are either gasoline-based or diesel-based. Depending on what type of fuel a vehicle burns, emissions are different. Generalitat de Catalunya has a mobility information site that offers information about average vehicle emission rates specific to Catalunya. Here, average CO_2 emission rates for diesel and gasoline vehicles during urban trips are specified:

Type of vehicle	Average CO_2 emission rate
Gasoline	308.5 gr CO_2/km
Diesel	177.9 gr CO_2/km

Table 5.1: CO_2 emission rates by vehicle type [Data source: (Gencat, 2009)].

With the information of Table 5.1, the private vehicle fleet in Catalunya has been examined. The share of diesel- and gasoline-based motorized vehicles is:

Type of vehicle	Share of total vehicles in Catalunya
Gasoline	50.0331%
Diesel	49.7252%

Table 5.2: Share of gasoline and diesel vehicles in Catalunya [Data source: (DGT, 2016)].

With the emission rates of each and their share in Catalunya, an average emission rate for all private vehicle in urban journeys can be determined:

$$\text{Average emission rate for private vehicles in Catalunya} = 242.81 \text{ gr } CO_2/\text{km}$$

The total CO_2 emissions for private vehicle urban trips in the scope of analysis can be calculated:

$$\text{Total } CO_2 \text{ emissions} = \text{Total traveled distance} \cdot \text{Average emission rate} \tag{5.3}$$

5.1.2 Projected situation

The flow diagram below shows the methodology to determine the project situation in terms of reduction in vehicles on the roads, total traveled distances and GHG emission reduction.

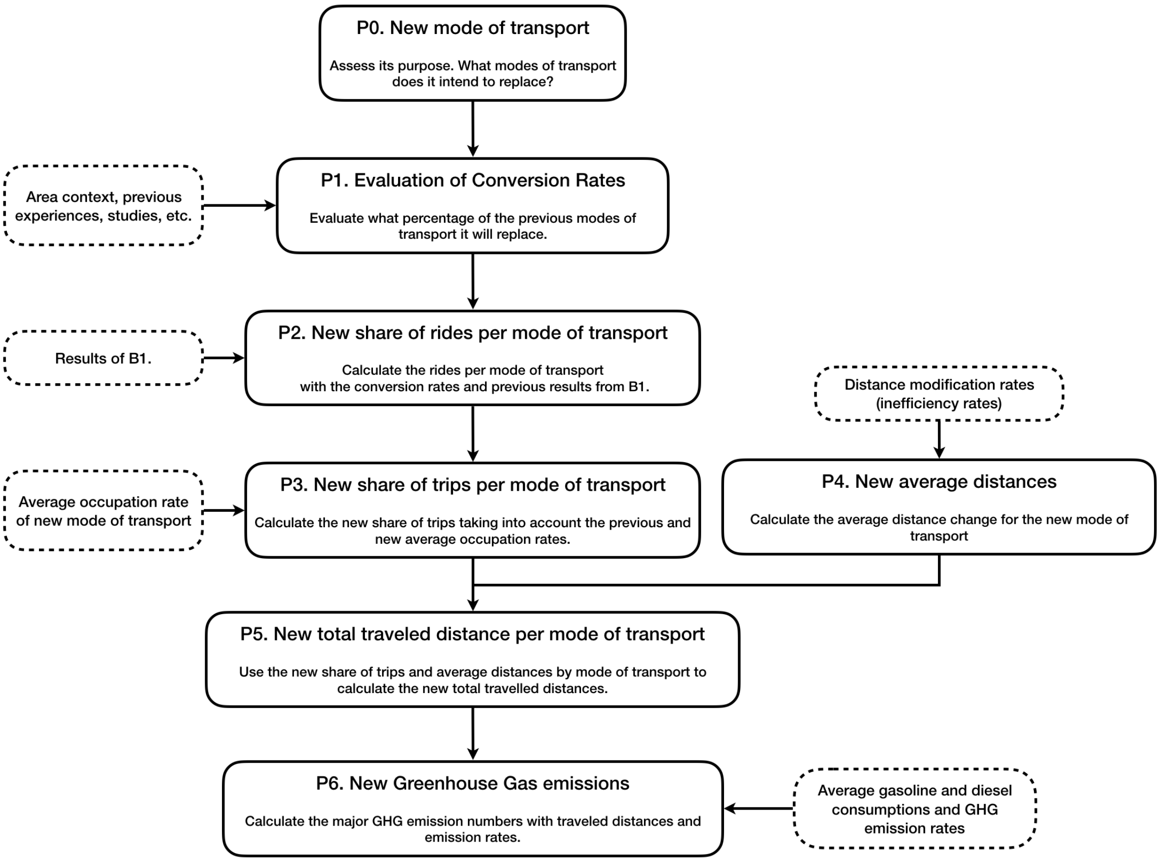

Figure 5.3: Second phase of the methodology, calculation of the projected situation.

Step P0

It is of utmost importance to have a clear strategy what is the modal shift that the new transportation system intends to provoke. In the case study of this report, the intended modal shift is from private vehicles to microtransit.

Step P1

The conversion rate determined the share of private vehicle trips will be covered with the microtransit service. This rate will be responsible for an important part of the results obtained. Microtransit, as it is conceived in this report, is a fairly new transportation service, so there are not many cases with enough collected data to estimate based on experience this conversion rate. The MaRS "Discovery District and Richmond Sustainability Initiatives" organization in

Canada, carried out an analysis of the impact of microtransit in the greater Toronto and Montreal areas (MaRS, 2016). In this report, they estimate an adoption rate of microtransit of 20%. In this report, a more conservative approach has been carried out, where microtransit improves its performance progressively on a 5-year period.

In the scope of analysis (Section 4.2), the ninety-nine municipalities are divided into 5 main groups (A, B, C, D, E), depending on average population sizes (A containing the largest municipalities and E the lowest). At the same time, an analysis carried out by AMTU identifies municipalities with potential for on-demand services based on whether there are neighborhoods in big municipalities with a poor public transport connection or whether there large fractions the surface of municipalities with an abundance of residential areas with the potential to create on-demand mobility patterns (AMTU, 2011). Based on municipality size and the potential of each for microtransit, the following table shows the Conversion Rates for this project:

Municipality group	Year 1	Year 2	Year 3	Year 4	Year 5
Group A	1%	2%	4%	5%	7%
Group B	3%	4%	6%	8%	10%
Group C	3%	6%	8%	10%	12%
Group D	5%	9%	11%	13%	16%
Group E	7%	10%	13%	16%	18%
On-demand potential	+3%				

Table 5.3: Conversion rates to microtransit on a 5-year period.

Table 5.3 shows that conversion rates increase with the decrease in average population sizes (Group E has higher conversion rates that Group A). This is because in the smaller municipalities, there is a much higher dependence on private vehicles and public transit performs the worst. It is expected that the microtransit service will be more successful in the most car-dependent municipalities and in those where there is a clear lack of coverage of accessibility of public transportation. At the same time, the conversion rates increase with time, and there is an added 3% in all towns with studied potential for on-demand services. One can see in Table 5.3 that conversion rates never reach the estimated 20% of the study carried out by (MaRS, 2016).

Step P2

Taking into account the results obtained in Step B1 and with the conversion rates of Table 5.3, the new share of private vehicles and microtransit on a 5-year period can be obtained.

$$\text{Number of microtransit rides} = \text{Number of private vehicle rides in B1} \cdot \text{Conversion rates} \quad (5.4)$$

Step P3

Here, the **average occupancy** for the microtransit needs to be determined. In Section 4.4 a 12-seat capacity Mercedes Sprinter van is proposed. In the (MaRS, 2016) study, an average vehicle occupancy of 6 is used. This project takes a more optimistic approach by setting the average occupancy of microtransit in **7 persons**. The new share of private vehicle and microtransit trips can be calculated following the equation (5.1) in this report.

Step P4

To calculate the average distance of each microtransit trip, the average distance of a regular fixed-route bus trip has been calculated. Then, since microtransit detours constantly to make pickups, to calculate the average distance, one can calculate the average distance for fixed-route routes line and then add an **Inefficiency Coefficient** that describes the distance that the microtransit service is detouring compared to a regular bus line. For the calculation of a fixed-route bus line, a similar process than to calculate the distance for each private vehicle trip has been carried out. As a reference for the iteration, information about public bus lines in Barcelona have been retrieved. Nowadays, there are 98 bus lines that cover a distance of 833.17 km (TMB, 2018a). With this numbers, it has been found that each bus lines roughly covers the diameter of the city if the city's surface area was a perfect circle. Therefore, the average distance for every bus trip has been estimated to be the diameter of each municipality's surface area if they were circular.

Then, Inefficiency Coefficients have been determined. Same as with the Conversion Rates estimated before, a criterion based on population size has been developed. In this case, in the larger towns lower inefficiencies will be estimated and as towns become smaller, population densities decrease and demand for transport scatters, inefficiencies rise. In the (MaRS, 2016) study, they estimate an Inefficiency Coefficient of 10%. This report has a more conservatives approach, where inefficiencies rise up to 30%. The following table shows the inefficiency rate for each population group.

Municipality group	Inefficiency Coefficient
Group A	10%
Group B	15%
Group C	20%
Group D	25%
Group E	30%

Table 5.4: Inefficiency coefficients of microtransit per population size group.

The average distance for each microtransit trip can be calculated:

$$\text{Average distance microtransit} = \text{Average distance bus line} \cdot (1 + \text{Innefficiency Coefficient}) \quad (5.5)$$

Step P5

With the newly calculated average distances in step P4, following the same process as in step B4, the total projection of traveled distances by private vehicles and the microtransit service in the whole scope of analysis can be calculated.

Step P6

To calculate the Greenhouse Gas emissions of the projected situation, one must have into account the new total traveled distance both private vehicles and microtransit services needs to be taken into account and multiplied by their emission rates. For the private vehicles, the same average CO_2 emission rate used in Step B5 is used. For the microtransit service, the average urban trip emission rate for a Mercedes Sprinter van has been used (Arpem, 2018). The following table shows the CO_2 emission rates used for private vehicles and the microtransit service.

Mode of transport	CO_2 emissions rate
Private vehicles	242.81 gr CO_2/km
Microtransit service	217 gr CO_2/km

Table 5.5: CO_2 emissions rates for private vehicles and the microtransit service.

With the determined CO_2 emission rates and total traveled distances by mode of transport, following the same process as in Step B5, the new total Greenhouse Gas emissions of the projected situation can be calculated.

5.1.3 Difference between baseline and projected situations

The following flow-diagram shows the methodology to calculate the difference between the baseline situation and the project, and hence, calculate the traffic and environmental impact.

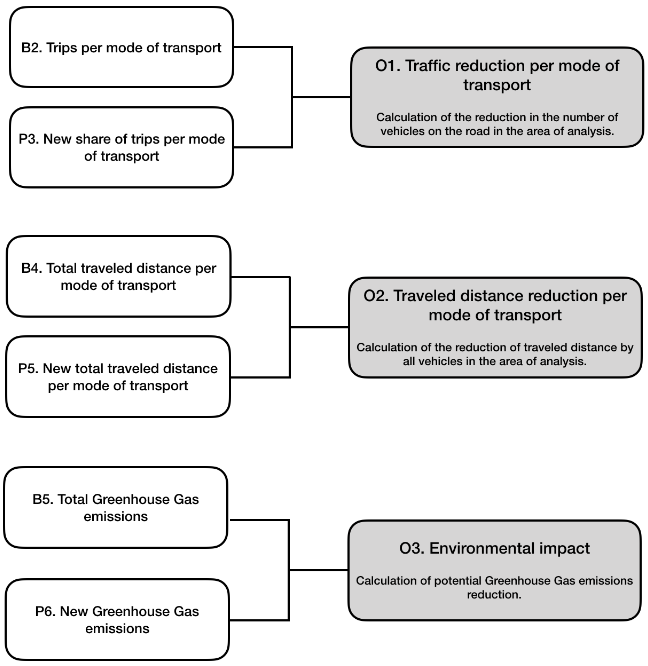

Figure 5.4: Third phase of the methodology, calculation of the traffic and environemntal impacts.

In the last phase of the methodology one must simply compare the results obtained in the previous two phases (as one can see in Figure 5.4).

Outcome 1 - Traffic reduction

The number of private vehicle trips calculated in Step B2 will be higher than the number of private vehicle trips plus the number of microtransit trips calculated in Step P3. The substraction of the baseline minus the projected situation will give the traffic reduction on the roads.

Outcome 2 - Traveled distance reduction

Same as with total trips, the total traveled distance adding up microtransit and private vehicles in Step P5 should be shorter than the total distance covered by private vehicles in the baseline situation. The subtraction of both gives the potential reduction in distance of all vehicles in the system to cover the same number of rides.

Outcome 3 - Environmental impact

The potential reduction of GHG emissions (CO_2 emissions specifically) that would result in the implementation of the described microtransit service in Chapter 4, for a 5-year time period with a progressive adoption rate, is calculated.

The difference between the total CO_2 in the baseline and projected situations gives the GHG emissions reduction of the case study.

5.2 Results

This section presents the main results derived from following the explained methodology.

First, the traffic, total traveled distance and GHG emissions resulting from the private vehicle mobility in each population group for a full year of the baseline situation will be presented.

Population group	**Number of rides [millions]**	**Number of trips [millions]**	**Total traveled distance [million kms]**	**GHG emissions [t CO_2]**
Group A	285.9	156.2	560.7	136,149
Group B	259.5	141.8	422.0	102,461
Group C	305.2	166.8	374.8	91,008
Group D	234.0	127.9	292.0	70,887
Group E	125.5	68.6	155.6	37,792
Total	1,210.3	661.3	1,805.1	438,298

Table 5.6: One-year baseline results of trips, total traveled distance and GHG emissions.

One can see that the number of rides and trips, and the traveled distance need to be counted in millions, which helps understand the size of the scope of analysis. Group A (municipalities with more than 100,000 people) are the ones that generate the most traffic and create the most CO_2 emissions. All measured magnitudes decrease in the subsequent groups where less traffic is generated.

With the presented implementation projection during a 5-year period, the savings in traffic, traveled distance and GHG emissions are shown in the below.

Timeline	**Trips savings [millions]**	**Traveled distance savings [million kms]**	**GHG emissions [t CO_2]**
Year 1	- 25.3	- 31.8	- 9,298
Year 2	- 36.5	- 44.3	- 12,947
Year 3	- 46.7	- 57.6	- 16,778
Year 4	- 55.9	- 68.6	- 20,003
Year 5	- 66.6	- 82.3	-23,981

Table 5.7: Traffic, total traveled distance and GHG emissions savings on a 5-year projection.

The number of rides is not displayed in Table 5.7 because the methodology contemplates an unchanged scenario of total rides, but a shift in how these rides are being serviced. One can see that savings increase progressively, to reach a potential final scenario shown in the following table, that shows the overall savings in traffic traveled distance and GHG emissions by population group.

Population group	**Number of trips [millions]**	**Total traveled distance [million kms]**	**GHG emissions [t CO_2]**
Group A	- 11.5	- 22.1	- 6.249
Group B	- 13.6	- 20.1	- 5,786
Group C	- 16.3	-16.6	- 4,874
Group D	-15.4	- 14.9	- 4,467
Group E	- 9.4	- 8.5	- 2,606

Table 5.8: 5-year projection results of trips, total traveled distance and GHG emissions savings by population group.

The municipalities in population Groups A and B are the ones with most CO_2 emissions savings potential. On the other hand, the chunk of municipalities in Group E have the least savings potential under the given conditions in the present report.

In absolute numbers, Tables 5.7 and 5.8 shows that CO_2 emissions potential can be counted in thousands of tones and the number of trips and total traveled distance savings are in the factor of millions.

To put into perspective the environmental impact potential of the microtransit service proposal, the following table shows the relative savings (in percentage) for each measured magnitude, taking the baseline calculation results as reference.

Trips savings	**Traveled distance savings**	**GHG emissions savings**
10.07 %	4.56 %	5.47 %

Table 5.9: Relative savings percentages of trips, traveled distances and GHG emissions.

Savings potential in GHG emissions accounts for over 5% of the total GHG emissions in the baseline calculation. Traveled distances can be shortened by just below 5% and traffic can be reduced by 10%. A deeper evaluation and interpretation of the obtained results is carried out in Section 5.3 (Discussion).

5.3 Discussion

The following plot shows the CO_2 emissions by population group and the total accumulative emissions for the baseline situation for one year.

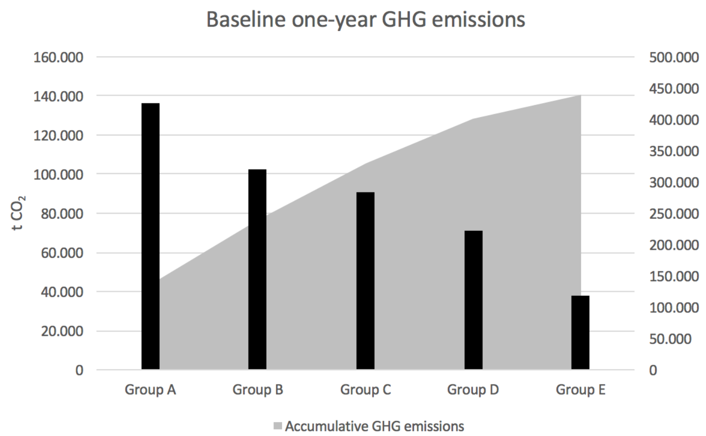

Figure 5.5: Baseline accumulated and by population group CO_2 emissions for one year.

The largest municipalities in the scope of analysis (Group A and B) account for more than 50% of all emissions, which explains why the GHG emissions savings are the highest in these municipalities. Although Conversion Rates in these municipalities are the lowest, See Table 5.3, the higher traffic volume makes them have the most emissions savings potential. Regarding the environmental impact of the whole microtransit service proposal, relative savings compared to the baseline situation are moderate. There has been an estimated reduction potential in vehicle trips savings of roughly 10%, the total traveled distance of all vehicles have a potential reduction of 5% and potential GHG emissions savings account for 5%.

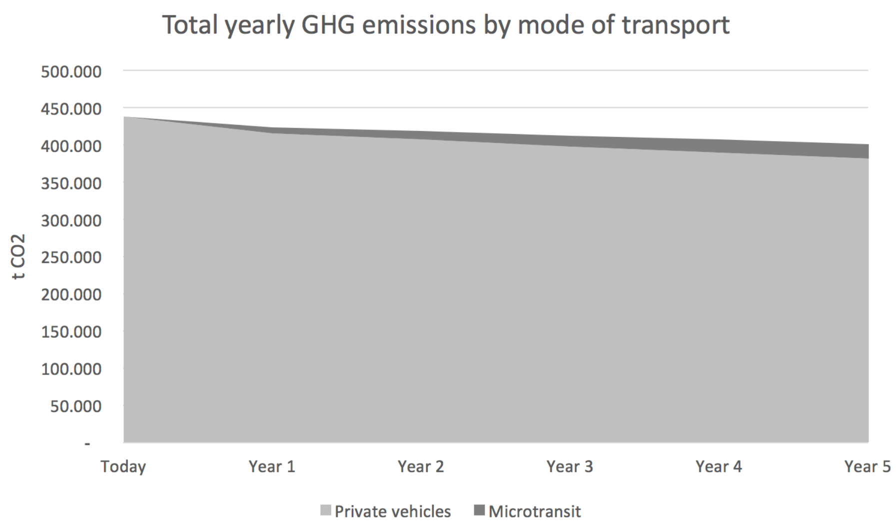

Figure 5.6: Total yearly CO_2 emissions by mode of transport.

Figure 5.6 shows that the yearly projection of GHG emissions savings, under the conditions explained in the Methodology, are moderate, where the majority of the CO_2 are still accounted to private vehicle trips, and a low fraction of the emissions comes from the microtransit service.

If the only objective of the microtransit proposal was to result in a more powerful environmental impact (see objectives in Section 4.1), the geographical area of deployment would have been denser population areas where the traffic volume is much higher. But the contexts in which microtransit can perform best overall (by answering to current lack of collective transport availability, enhancing accessibility and coverage, and saving GHG emissions) are not the densest areas, where there already are many options for private and collective transportation. Thus, when deciding the geographical scope of analysis, the densest areas of the metropolitan area of Barcelona were left out to be coherent with the main theoretical findings and conclusions, which identify the most convenient contexts for microtransit.

Deepening more into the implementation area of the microtransit service, if microtransit was implemented in denser and more populated areas, Inefficiency Coefficients (see Table 5.4) would have been lower, as there would have been many more ride requests in closer areas and the algorithm would be able to create on-demand straighter routes, with shorter detouring distances to arrange more pickups. On top of this, the adoption rate of this new service would have been higher, as it would have become a more convenient service for more riders. However, it would be very likely that an unintended modal shift would have occurred, and many high-capacity public transit riders would have shifted to smaller vehicle capacity microtransit services. This could have a reverse environmental impact because average vehicle occupancy would decrease, and more vehicles would be running in the already dense urban roads. Therefore, although it would seem that only considering the environmental impact, it would be wiser to deploy microtransit collective transportation systems in denser areas, this is not a clear fact, as it could have an adverse effect by increasing the number of vehicles on the roads.

Coming back into the reasons behind having a moderate 5% reduction in CO_2 emissions, one must note the effect of the Conversion Rates and Inefficiency Coefficients on the GHG emissions savings potential of the system. If one looks at the Conversion Rates (Table 5.3), one will see that they never exceed 20%, in the majority of cases being much lower. In a 5-year period, this results in an overall adoption rate (number of rides that were serviced by private transport that are replaced by microtransit services) of just above 15%. The table below shows the adoption rate progression in the 5-year period.

Timeline	Private vehicle rides [millions]	Microtransit rides [millions]	Adoption rate
Today	1,210	0	0%
Year 1	1,147	63	5.46 %
Year 2	1,120	90	8.08 %
Year 3	1,094	116	10.59 %
Year 4	1,072	138	12.92 %
Year 5	1,045	165	15.79 %

Table 5.10: Private vehicle rides, microtransit rides and adoption rate per year.

With a total accumulated adoption rate of just above 15%, it is reasonable to have results of 10% of traffic reduction and 5% of CO2 emissions savings.

One of the priorities of the microtransit service proposal was to offer a quality service by decreasing the distances of operation, by only aiming to service urban trips (inside municipality boundaries). This way rides request should always have microtransit vehicles relatively close; therefore, waiting times should be low and the service quality should be high enough to become convenient for a significant fraction of all daily rides inside municipalities. The following figure shows the distribution of all urban trips done in all municipalities in the scope of analysis.

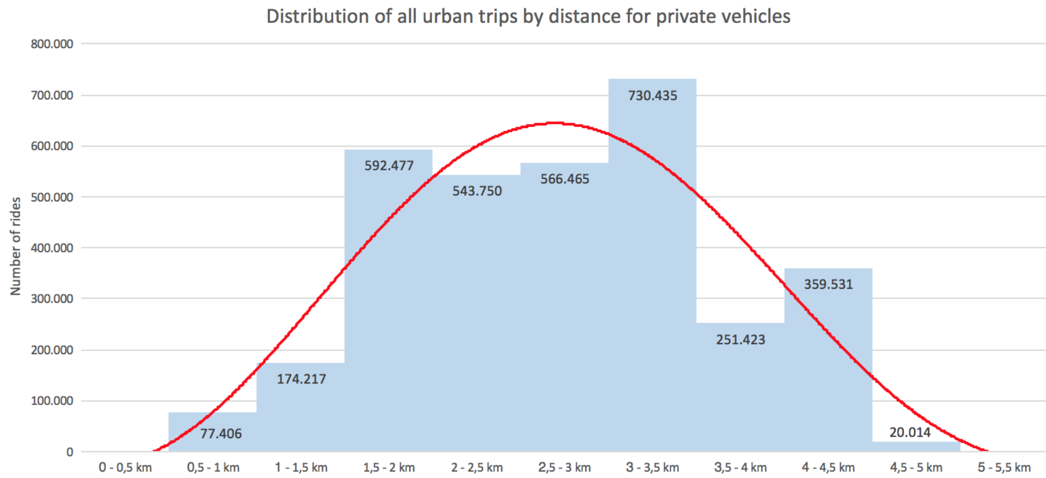

Figure 5.7: Distribution of all urban trips by distance for private vehicles.

Figure 5.7 shows that the majority of the urban trips in the scope of analysis are between 1.5 and 3.5 km. This relatively short distance should favor the quality of the microtransit service. Therefore, the 15% adoption rate showed in Table 5.10 is moderate (compared to the 20% that the study (MaRS, 2016) predicts), but looks achievable by the nature of the trips distances that the microtransit service aims to cover.

Regarding the effect of the Inefficiency Coefficients (see Table 5.4) in the GHG emissions savings potential, the following plot shows the absolute values of potential vehicle trips (traffic) reduction and GHG emissions savings potential of each municipality group after the projected 5-year period.

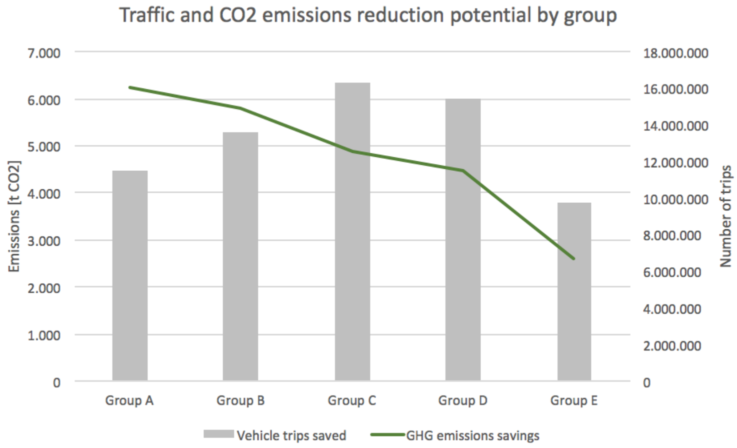

Figure 5.8: Trips and GHG emissions savings by population group.

Figure 5.8 shows that when it comes to traffic savings, municipalities in Groups B, C and D reduce the number of vehicle trips on the roads at a higher level than Group A (Group E does not show more significant reduction values because the traffic is already much lower than in the other municipalities). However, this higher vehicles trips reduction does not have such effect on GHG emissions savings. This is due to the applied Inefficiency Coefficients. As municipalities get smaller, population densities decrease and demand for rides is more scattered; thus, the amount of extra traveled distance by microtransit vehicles to arrange pick-ups and drop-offs becomes longer. This extra distance needs to be factored in via the Inefficiency Coefficients. For this reason, one can see that although absolute values of traffic reduction can be higher in smaller municipality groups (due to the Conversion Rates), the Inefficiency Coefficients limit the potential for GHG emissions savings.

The average vehicle occupancy rates also play an important role in the environmental impact of the system. The methodology explains that 1.83 people/vehicle private trips are intended to be replaced with a 7 person/vehicle microtransit proposal. In theory, if these vehicles had higher capacities (like fixed-route bus lines) the number of vehicles on the road should decrease more significantly and the CO_2 emissions savings potential should increase more considerably. However, if larger vehicles were proposed, since in the geographical area of analysis demand is low and scattered, adoption rates would not increase, and the system would have over-sized vehicles in operation being driven around these municipalities, traveling half empty and consuming much more fuel than necessary (which is similar to the current situation of fixed-route bus lines today).

The proposed microtransit system alone, using a Mercedes Sprinter diesel van, can potentially result in significant absolute values of GHG savings, although moderate from a relative perspective compared to the baseline situation. If the microtransit system was combined with the electrification of transport, having electric vehicles running the flexible routes, the savings potential would be subject to a more notable increase. With an average associated CO_2 emissions rate of 130 g CO2/km (Gencat, 2009), the potential GHG emission reduction could increase by 160%. In this situation, the traffic reduction potential and total traveled distance would remain the same, because, naturally, electrification of transport does not result in fewer vehicles on the road, but in a lower environmental impact of their operation.

Chapter 6

Conclusions

The technological advancements and business innovations of the present have opened an opportunity for microtransit to become a promising alternative for collective transportation if implemented in specific contexts (low population density areas with scattered demand for transportation) and with adequate goals (improve coverage and accessibility in areas that lack mobility services, offer last mile and connection services with high-capacity means of transport, increase ridership and economic viability in coverage-driven areas, etc.).

Nowadays, the philosophy behind designing transportation modes is different from the tendency of the 20th-century. Before, transportation development was based on expansion, namely, building new roads and rails, and mass-producing motorized vehicles for private usage. Today, we understand that expansion cannot enhance the quality of mobility and that we must harness the full potential of our available resources to design high-quality and efficient transportation systems that generate the least negative impacts on the environment and on our living conditions.

Hence, when designing transportation systems in urban areas, it is paramount to understand clearly the goals that want to be achieved, the context of each designated area and which transportation means are the most adequate for each situation. In high-density population centers, high-capacity modes with ease of access are the most adequate (metros, trams and articulated buses). To connect high-density areas with less populated outer zones, long-distance, lower-frequency and high-capacity modes are recommendable (commuter trains, articulated buses and long metro lines). Throughout low-density areas, smaller and more adaptable vehicles are the most adequate (regular and microbuses). In many low-density areas with scattered demand, regular fixed-route buses cannot meet mobility needs; here, an opportunity for microtransit arises.

Shared mobility solutions are increasing the level of service of collective transportation. Vehicle-sharing services (such as DriveNow, Drivy, Cityscoot or eCooltra) increase the efficiency of vehicle fleets and ride-sharing services (such as Uber, Didi Hitch or Bla Bla Car) intend to increase car-occupancy rates and decrease traffic. Microtransit is categorized inside this latter group.

Microtransit uses mid-sized vehicles to offer flexible and dynamic routes that adapt to users' locations and schedules. This type of transport systems takes advantage of the IT-enabled services to connect demand and supply in real-time. The conditions in which microtransit is the most effective to improve transportation in a certain area are low and scattered demand areas where fixed-route bus lines cannot offer convenient transportation. In these situations, microtransit can offer quality coverage while maximizing ridership, see Figure below.

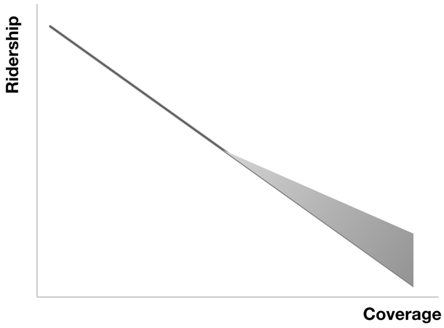

Figure 6.1: Influence of microtransit on the qualitative trade-off between ridership and coverage. [Source: Conversation with private microtransit company, Shotl]

However microtransit comes with various challenges. If it is implemented inside a different context (city centers, etc.), there is the risk of people shifting from public transport to microtransit, digital divide can also be a serious problem and high route inefficiencies can make the system less environmentally sustainable.

There are many companies worldwide and at a local-scale that are experiencing with microtransit. Some follow completely private interests, which can potentially be detrimental for the overall transportation system of a certain urban area (i.e. Chariot or Via). Other microtransit companies work with municipalities and public agencies to align their private interests with the mobility needs of specific urban areas (i.e. TransLoc or Shotl).

A case study has been proposed where mobility data of 99 municipalities in the outer metropolitan area of Barcelona has been analyzed. In all municipalities there is a high dependency on private transportation and fixed-route public transport cannot meet the mobility needs of citizens in these municipalities. A microtransit service has been proposed that pursues the following principles:

- Integrated with other means of public transport
- Multi-platform based service
- Focused on short distance urban travel
- Multimodal
- Live and flexible routing algorithm
- Small-capacity vehicles

Then, the potential environmental and traffic effects of such a system in the proposed geographical area of analysis has been evaluated. In order to do so, a general methodology has been proposed that guides the user through the steps that need to be followed to assess the potential environmental impacts of a new transportation system in a certain geographical area. The methodology has been followed for the analysis of the case study and potential effects on traffic and CO_2 have been drawn.

From an initial scenario of a total of 1.2 billion rides, which account for 661 million private vehicle trips per year, resulting in 438 t CO_2; the microtransit service has estimated to be adopted by roughly 15% of the trips on a 5-year projection. At the end of this 5-year period, a 10% reduction in traffic, a 4.5% reduction in the total traveled distance by all vehicles in the system and a CO_2 emissions savings potential of 5% has been projected.

These results, though unexceptional, show the traffic and GHG emissions savings potential of microtransit. High inefficiency rates (up to 30% in the least populated areas), predicted low adoption rates (a total of 15%) and a modest vehicle occupancy rate for the proposed microtransit service (compared to fixed-route public transportation) have resulted in the moderate traffic and emissions reduction values.

Nevertheless, while moderately contributing to the goal of reducing car trips and saving GHG emissions, such a system proposal meets, at the same time, other social goals that make microtransit a comprehensive mobility solution. In many areas of the 99 analyzed municipalities, with the proposed microtransit system in place, public transportation can offer accessibility and a wider coverage to many isolated and car-dependent citizens that were previously never reached with fixed-route transit.

Thus, public transportation planners have in microtransit a firm alternative to solve the ever-conflicting issue of how to offer quality collective transportation services in low-density and scattered demand areas.

Future work

The subsequent paragraphs raise issues that have come up during the elaboration of the project that are not assessed in this report but are of great interest to be analyzed in the future.

- A comprehensive analysis of the decision-making process of microtransit routing and optimization algorithms could be carried out. From finding optimal routes and vehicle designations to figuring the limitations of long can one make potential riders walk to virtual stops, what are the tolerable waiting times and how can coordination happen with other means of transport, are areas of study that could follow up the present report.
- A further development of the showcase microtransit examples of the report could be performed, by analyzing closely all transportation and mobility in a specific municipality, designing the deployment of entire microtransit service, and possibly, implementing a pilot project at a small representative scale.
- A pilot project comparison of the deployment of microtransit services in two different municipality typologies, in terms of potential for multimodality, traffic reduction, and environmental impacts. For example, the comparison between a municipality of fewer than 10,000 people with another one with a population higher than 50,000.
- The assessment of how to carry out new urban planning taking into account the current capabilities of transportation services.
- How will autonomous driving affect mobility, the public transportation sector, and microtransit.

References

AMB. (2013). *Quadern de la mobilitat - cerdanyola del vallès.* http://www.amb.cat/documents/11704/1121892/Quadern+mobilitat+Cerdanyola.pdf/9cb8380d-c1c9-4e7d-8765-746eec116899. ((Accessed on 09/10/2018)) 8, 62, 63, 64

AMB. (2018). *Quadern de la mobilitat - corbera de llobregat.* http://www.amb.cat/documents/11704/1121892/Quadern+mobilitat+Corbera+de+Llobregat.pdf/19be5d7e-2c1f-4064-b177-2d3c555c63a2. ((Accessed on 09/11/2018)) 8, 67, 68, 69, 70

AMTU. (2011, February). *Resum executiu amtu tpd.* https://www.amtu.cat/infoweb/estudis/RE-TAD.pdf. ((Accessed on 08/27/2018)) 49, 50, 56, 81

AMTU. (2012, November). *Dossier amtu 2011.* https://www.amtu.cat/dossier-amtu/1784-dossier-amtu-2011. ((Accessed on 09/02/2018)) 7, 52, 53, 54

AMTU. (2013a, September). *Emia 2013.* https://www.amtu.cat/infoweb/estudis/EMIA-2013-Resum.pdf. ((Accessed on 09/15/2018)) 78

AMTU. (2013b). *Enquesta de mobilitat interurbana ambit amtu (2013).* https://www.amtu.cat/enquestes-de-mobilitat-interurbana/1274-enquesta-de-mobilitat-interurbana-a-l-ambit-amtu-2013. ((Accessed on 09/03/2018)) 55, 56

Arpem. (2018). *Datos y ficha tecnica mercedes-benz sprinter 319 bluetec combi medio t.e. 190 cv.* https://www.arpem.com/mercedes/sprinter-2013/furgonetas/mercedes-benz-sprinter-319-bluetec-combi-medio-t-e-190-cv.html. ((Accessed on 09/15/2018)) 83

ATM. (2015). *Enquesta de mobilitat en dia feiner 2015.* https://doc.atm.cat/ca/_dir_emef/emef2015/files/assets/basic-html/page-1.html#. ((Accessed on 09/15/2018)) 8, 9, 55, 77

ATM. (2016). *Enquesta de mobilitat en dia feiner 2016.* https://doc.atm.cat/ca/_dir_emef/emef2016.pdf. ((Accessed on 08/26/2018)) 48

Autocorb. (2018). *Horarios - linias regulares.* http://www.autocorb.com/es/horarios/. ((Accessed on 09/13/2018)) 68

Bella, B. (2017, July). *Can barata estrena transport a la demanda per connectar el barri amb s.* http://www.totsantcugat.cat/actualitat/mobilitat/can-barata-estrena-transport-a-la-demanda-per-connectar-el-barri-amb-s_169575102.html. ((Accessed on 07/31/2018)) 43

BlaBlaCar. (2018). *Nuestra historia: los origenes de blablacar.* https://www.blablacar.es/conoce-blablacar/nuestra-historia. ((Accessed on 06/13/2018)) 23

Bliss, L. (2017, November). *Microtransit lands in arlington, texas with via partnership - citylab.* https://www.citylab.com/transportation/2017/11/a-bus-shunning-texas-towns-big-leap-to-microtransit/546134/. ((Accessed on 07/19/2018)) 33

Bridj. (2018). *Our story.* https://www.bridj.com/journey/. ((Accessed on 07/29/2018)) 41

Bruglieri, M., Colorni, A., & Lue, A. (2014). The vehicle relocation problem for the one-way electric vehicle sharing: An application to the milan case. *Procedia - Social and Behavioral Sciences*, *111*, 18 - 27. Retrieved from http://www.sciencedirect.com/science/article/pii/S1877042814000354 (Transportation: Can we do more with less resources? 16th Meeting of the Euro Working Group on Transportation Porto 2013) doi: https://doi.org/10.1016/j.sbspro.2014.01.034 22

Cerdanyola, A. (2018). *Xarxa geodesica.* http://sig.cerdanyola.cat/cerdanyolagis/visor-geodesic.jsp. ((Accessed on 09/10/2018)) 8, 62

Chariot. (2018). *Chariot - about us.* https://www.chariot.com/about. ((Accessed on 07/24/2018)) 39

Clewlow, R. R., & Mishra, G. S. (2017). *Disruptive transportation: the adoption, utilization, and impacts of ride-hailing in the united states* (Tech. Rep.). Research Report–UCD-ITS-RR-17. 24

Crunchbase. (2018a). *Bridj | crunchbase.* https://www.crunchbase.com/organization/bridj#section-overview. ((Accessed on 07/29/2018)) 41

Crunchbase. (2018b). *Chariot company information.* https://www.crunchbase.com/organization/chariot-4#section-overview. ((Accessed on 07/24/2018)) 39

Crunchbase. (2018c). *Didi chuxing.* https://www.crunchbase.com/organization/didi-dache#section-overview. ((Accessed on 06/13/2018)) 23

Crunchbase. (2018d). *Lecab | crunchbase.* https://www.crunchbase.com/organization/lecab#section-overview. ((Accessed on 07/29/2018)) 41

Crunchbase. (2018e). *Shotl | crunchbase.* https://www.crunchbase.com/organization/shotl#section-overview. ((Accessed on 07/31/2018)) 42

Crunchbase. (2018f). *Transloc | crunchbase.* https://www.crunchbase.com/organization/transloc#section-overview. ((Accessed on 07/30/2018)) 42

Crunchbase. (2018g). *Via | crunchbase.* https://www.crunchbase.com/organization/via-transportation#section-overview. ((Accessed on 07/29/2018)) 40

Daniels, R., & Mulley, C. (2013). Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use*, *6*(2), 5–20. 32

DGT. (2016). *Tablas estadisticas - parque de vehiculos.* http://www.dgt.es/es/seguridad-vial/estadisticas-e-indicadores/parque-vehiculos/tablas-estadisticas/. ((Accessed on 09/15/2018)) 9, 79

English, N. (1995). *Learning from experiences with transportation management and traffic engineering : a systematic approach to planning energy efficient transport improvements.* Sittard: Centre for the Analysis and Dissemination of Demonstrated Energy Technologies. 7, 18, 19

EPA. (2018, April). *Sources of greenhouse gas emissions | greenhouse gas (ghg) emissions.* https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions. ((Accessed on 09/19/2018)) 1

Gencat. (2009, October). *Movilidad y emisiones. movilidad. generalitat de catalunya.* http://mobilitat.gencat.cat/es/detalls/Article/mobilitat_emissions. ((Accessed on 09/15/2018)) 9, 79, 90

Hawkins, A. J. (2016, January). *It took uber five years to get to a billion rides, and its chinese rival just did it in one - the verge.* https://www.theverge.com/2016/1/11/10749282/didi-kuaidi-rideshare-billion-rides-2015-china-competitor. ((Accessed on 06/13/2018)) 23

Idescat. (2018, July). *El municipio en cifras - institut estadistica catalunya - generalitat de catalunya.* https://www.idescat.cat/emex/?lang=es. ((Accessed on 08/14/2018)) 61, 67

ITDP. (2018). *What is brt? - institute for transportation and development policy.* https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/. ((Accessed on 06/05/2018)) 19

Jin, S. T., Kong, H., Wu, R., & Sui, D. Z. (2018). Ridesourcing, the sharing economy, and the future of cities. *Cities*, *76*, 96 - 104. Retrieved from http://www.sciencedirect.com/science/article/pii/S0264275117311952 doi: https://doi.org/10.1016/j.cities.2018.01.012 7, 21, 23

Kelleher, S. R. (2018, April). *Scooter sharing is the unlikely trend that'll reshape the way we travel - condÃ© nast traveler.* https://www.cntraveler.com/story/scooter-sharing-is-the-unlikely-trend-that-will-reshape-the-way-we-travel. ((Accessed on 06/11/2018)) 22

LeCab. (2018a). *Book your minicab transfer: Take a cab to any of the paris train stations - cheaper than a taxi ride.* https://en.lecab.fr/our-services/cab-gare-paris-price.html. ((Accessed on 07/30/2018)) 41

LeCab. (2018b). *Call a cab for airport transfer with lecab.fr, better than a taxi.* https://en.lecab.fr/our-services/airport-transfer-paris.html. ((Accessed on 07/30/2018)) 41

LeCab. (2018c). *https://en.lecab.fr/our-services/our-services-vtc-france.html.* https://en.lecab.fr/our-services/our-services-vtc-france.html. ((Accessed on 07/30/2018)) 41

Lee, T. B. (2015, April). *Uber lost \$2.8 billion in 2016. will it ever become profitable? - vox.* https://www.vox.com/new-money/2017/1/9/14194202/uber-lost-22-billion-9-months. ((Accessed on 06/26/2018)) 26

MaRS. (2016). *Microtransit: An assessment of potential to drive greenhouse gas reductions* (Tech. Rep.). MaRS Discovery District and Richmond Sustainability Initiatives. 24, 35, 81, 82, 89

Misachi, J. (2017, September). *The most densely populated cities in europe - worldatlas.com.* https://www.worldatlas.com/articles/the-most-densely-populated-cities-in-europe.html. ((Accessed on 08/26/2018)) 48

Poushter, J. (2017, April). *Smartphones are common in advanced economies, but digital divides remain | pew research center.* http://www.pewresearch.org/fact-tank/2017/04/21/smartphones-are-common-in-advanced-economies-but-digital-divides-remain/. ((Accessed on 06/26/2018)) 25

Rao, S. (2016, October). *London new late night alternative: The night tube + uber.* https://medium.com/uber-under-the-hood/londons-new-late-night-alternative-the-night-tube-uber-8f38e56de983. ((Accessed on 06/13/2018)) 24

Ribeiro, P., & Rocha, V. (2013). Flexible public transport in low density urban areas. *Recent Advances in Engineering Mechanics, Structures and Urban Planning*, 169–174. 20

Rissanen, K. (2016). Kutsuplus–final report. *Helsinki: Helsinki Regional Transport Authority (HSL)*. 39

Rodrigue, J.-P., Comtois, C., & Slack, B. (2016). *The geography of transport systems.* Routledge. 16

Rodriguez, M. (2014, March). *Amb implantarÃ¡ transporte a la demanda en el prat.* http://www.carrilbus.com/noticias/402_10_amb_implantara_transporte_a_la_demanda_en_el_prat.php#sthash.eCPtuq1M.dpbs. ((Accessed on 07/31/2018)) 43

Roser, M., & Ortiz-Ospina, E. (2017, April). *World population growth - our world in data.* https://ourworldindata.org/world-population-growth. ((Accessed on 05/08/2018)) 13

Royale. (2018). *Sprinter shuttle bus | royale.* https://www.royalelimo.com/vehicles/MB-Sprinter-Mini-Coach-Bus.aspx. ((Accessed on 09/19/2018)) 8, 60

SCAQMD. (2018). *Smog and health-historical info.* http://www.aqmd.gov/home/research/publications/smog-and-health-historical-info. ((Accessed on 05/08/2018)) 13

Schmoeller, S., & Bogenberger, K. (2014). Analyzing external factors on the spatial and temporal demand of car sharing systems. *Procedia - Social and Behavioral Sciences*, *111*, 8 - 17. Retrieved from http://www.sciencedirect.com/science/article/pii/S1877042814000342 (Transportation: Can we do more with less resources? 16th Meeting of the Euro Working Group on Transportation Porto 2013) doi: https://doi.org/10.1016/j.sbspro.2014.01.033 22

Shontell, A., & Lebowitz, S. (2017, October). *How john zimmer and logan green started lyft - business insider.* http://www.businessinsider.com/how-john-zimmer-and-logan-green-started-lyft-2017-10?IR=T. ((Accessed on 06/14/2018)) 24

Shotl. (2016, July). *Shotl meets kutsuplus, the first real-time on-demand public transport in europe - youtube.* https://www.youtube.com/watch?v=h-pJqVwEEDM. ((Accessed on 07/24/2018)) 39

Shotl. (2018). *Mobility on-demand.* https://shotl.com/platform. ((Accessed on 07/31/2018)) 43

Smith, R. (2016, June). *Flexibility in the on-demand economy - national employment law project.* http://www.nelp.org/publication/flexibility-in-the-on-demand-economy/. ((Accessed on 06/14/2018)) 24

TMB. (2018a). *Datos del transporte de tmb | transports metropolitans de barcelona.* https://www.tmb.cat/es/sobre-tmb/conocenos/transporte-cifras. ((Accessed on 09/15/2018)) 82

TMB. (2018b). *T-mobilitat - billetes y tarifas.* https://www.tmb.cat/es/sobre-tmb/mejoras-red-transporte/t-mobilitat. ((Accessed on 08/31/2018)) 8, 56, 58

TransLoc. (2018). *About us - transloc.* https://transloc.com/about/. ((Accessed on 07/30/2018)) 42

Tsipori, T. (2017, January). *Transport-on-demand co via launches in paris - globes.* https://en.globes.co.il/en/article-transport-on-demand-co-via-launches-in-paris-1001174589. ((Accessed on 07/30/2018)) 41

Uber. (2018). *https://www.uber.com/newsroom/history/.* https://www.uber.com/newsroom/history/. ((Accessed on 06/13/2018)) 23

UN. (2014). *World urbanization prospects, [highlights].* https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf. 13

Vanguardia, L. (2018, March). *Barcelona tendrÃ¡ un 80 % de la flota municipal y 100 buses electricos en 2024.* http://www.lavanguardia.com/politica/20180314/441522757499/barcelona-tendra-un-80--de-la-flota-municipal-y-100-buses-electricos-en-2024.html. ((Accessed on 06/26/2018)) 26

Via. (2018). *Via | smarter shared rides.* https://ridewithvia.com/. ((Accessed on

07/29/2018)) 40

Walker, J. (2008). Purpose-driven public transport: creating a clear conversation about public transport goals. *Journal of transport geography*, *16*(6), 436–442. 15

Walker, J. (2017, July). *The dangers of elite projection.* http://humantransit.org/2017/07/the-dangers-of-elite-projection.html. ((Accessed on 07/20/2018)) 36

wbur. (2017, May). *Why boston-based bridj halted its on-demand shuttle service | bostonomix.* http://www.wbur.org/bostonomix/2017/05/02/bridj-shutdown. ((Accessed on 07/29/2018)) 41

Williams, R. (2017, June). *How uber works together with southern california growing rail network.* https://medium.com/uber-under-the-hood/how-uber-works-together-with-southern-californias-growing-rail-network-fa8b1aba03b4. ((Accessed on 06/13/2018)) 24