Escola de Camins
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Station as mobility hubs: Impact of transforming public spaces on the adoption of sustainable modes of transportation and promotion of intermodality

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Station as mobility hubs: Impact of transforming public spaces on the adoption of sustainable modes of transportation and promotion of intermodality

A Case Study

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Master's Thesis
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Resumen

El transporte público es el modo de transporte sostenible por excelencia para las masas. Pero a menudo se pasa por alto el papel de las infraestructuras de transporte público en la adopción de otros medios de desplazamiento sostenibles, como los compartidos. En realidad, tienen el potencial de ser centros de intermodalidad para los medios de transporte compartidos, como la micromovilidad. Se han realizado estudios para analizar el impacto de las soluciones de micromovilidad en los patrones de movilidad de los usuarios, especialmente para complementar el transporte público en la primera y última milla. Sin embargo, debido a una posible laguna en la investigación y a una aplicación ineficaz de estas novedosas soluciones de micromovilidad, el mayor potencial de utilización de los espacios asociados al transporte público para la intermodalidad está aún por descubrir.

Esta tesis tiene como objetivo comprender la intermodalidad en las estaciones de ferrocarril, que se induce al proporcionar espacios para soluciones de micromovilidad. Se realiza una amplia revisión de la literatura para identificar los diversos factores que facilitan la integración del transporte público y la micromovilidad. Se han examinado las sugerencias y recomendaciones formuladas en la bibliografía para mejorar y promover el éxito de la integración de la micromovilidad y el transporte público. Además, se han estudiado las repercusiones de las soluciones de micromovilidad en las estaciones de transporte público mediante el análisis de una implementación pasada y los cambios que indujo en el comportamiento de viaje de los viajeros al adoptar la micromovilidad para la primera y la última milla de su viaje. Los resultados revelan que la provisión de soluciones de micromovilidad en los centros de transporte público induce a los viajes intermodales, pero su influencia es limitada debido a la falta de infraestructura de apoyo.

Abstract

Public transportation is the ultimate sustainable mode of transportation for the masses. But the role of public transportation infrastructure is often overlooked in the adoption of other sustainable means of commute, such as shared. In reality, they have the potential to be hubs of intermodality for shared means of transport such as micro-mobility. There have been studies done to analyse the impact of micro-mobility solutions on the mobility patterns of users, especially for complementing public transportation in the first and last mile. But due to a possible research gap and an inefficient implementation of these novelty micro-mobility solutions, the larger potential of using the spaces associated with public transportation for inter-modality is yet to be uncovered.

This thesis aims to understand the intermodality in railway stations, that are induced by providing spaces for micro-mobility solutions. An extensive review of the literature is done to identify the various factors that facilitate the integration of public transport and micromobility. Suggestions and recommendations made in the literature to enhance and further promote the successful integration of micromobility and public transportation have been examined. Furthermore, the impacts of installing micromobility solutions in public transport stations are studied by analysing a past implementation and the changes it induced in the travel behaviour of the commuters in adopting micromobility for the first and last mile of their journey. The findings reveal that providing micromobility solutions in public transport hubs does induce intermodal travel, but its influence is limited due to a lack of supporting infrastructure.

Keywords Intermodality, Public Transport, Micromobility, Access, Egress, First-mile, Last-mile

Contents

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1 Introduction

From the industrial revolution of the eighteenth century to the revolutionary technology advancements of the twenty-first century, humans have significantly influenced the global evolution that is occurring. Despite the unparalleled advancement brought about by these developments, they have also aided in the deterioration of our world. But it's crucial to keep in mind that these human endeavours have also improved living conditions for people all around the world. Finding a balance between enabling a better life and preventing the destruction of the planet in cities is imperative, as an increasing number of people are moving to urban centres. The urban population is set to increase to almost 70% of the overall population, in the next 30 years (United Nations Department of Economic and Social Affairs, 2018).

The infrastructure that supports today's cities is likely to be under tremendous strain as a result of the population shift into urban regions. One of these infrastructures, if not the most crucial, is urban transportation. The quality of life depends on having access to basic resources and opportunities, and mobility serves as the link that connects residents to these resources. With an influx of population into the cities in search of better prospects, it is no surprise that cities contribute up to 70% of the global greenhouse gas (GHG) emissions (United Nations Human Settlements Programme (UN-Habitat), 2011).

To meet the needs of the ever-expanding urban population, governments across the world are constantly working on solutions for improving the efficiency of their urban transportation networks. With transportation being accountable for one-third of the GHG emissions in the major urban areas (OECD, 2020), a transition to sustainable urban mobility solutions is necessary. As prosperity spreads among the population, vehicle usage is going to increase exponentially. Cities, governments and other multinational organisations have been relentlessly working on policies to address this. The adoption of sustainable mobility development strategies is the balancing act that allows for human upliftment without damaging the environment.

Mobility is a necessity, but given the variety of options available to consumers, it is not surprising that most of the time sustainability is not a factor in picking a mode of transportation. The public must be provided with alternatives to discourage the ownership and use of private vehicles. Within this context, public transit is the obvious choice in urban areas. Public transportation has evolved from being the transportation of the masses to being the ultimate choice for sustainable commutes within the cities. Investments in public transportation and policies promoting its usage are crucial to cutting the emissions coming from the transportation sector (Jing et al., 2022).

For all the advantages that it offers compared to other modes of transportation, in terms of sustainability and user costs, public transport has some shortcomings that make it less attractive compared to personal modes of transport. One of the major issues associated with public transport is that it is less flexible (Currie & Fournier, 2020). Across the world, public transport runs on fixed routes and schedules, making it less versatile. Technological innovation in recent years had helped introduce dynamic routing and demand responsiveness in public transport, but it is still a long way from achieving a level of scalability and impact (Currie & Fournier, 2020).

Another significant issue with public transportation referred to as the first/last mile problem, is its inability to provide door-to-door connection, which drives people to use private transportation. Up until a few decades ago, the private transportation landscape was dominated by fossil fuel-powered cars. The dependence on fossil fuel-powered automobiles may decline in the future with a strong push toward electric vehicles. Aside from these private cars, there are other new modes of transportation or even some older ones that have advanced due to recent technological innovations, giving decision-makers more options to combat climate change from a mobility perspective. From the age-old human-powered bicycles of the past to the new electric-powered scooters, micromobility is the emerging trend in urban mobility.

Micromobility consists of bicycles, e-scooters, e-bikes and various other electric-powered micro vehicles (ITF, 2020). These can be for private use, as well as for shared use through public bike-sharing systems. Many cities throughout the world have implemented public bike-sharing programs to provide their residents with an alternate and environmentally friendly form of transportation. From just 17 systems worldwide in 2005, bike-sharing programs have grown to almost 3000 in 2019 (Galatoulas et al., 2020). With public transport ridership taking a hit due to the fear of infection during the early stages of the COVID-19 pandemic in 2020, alternative modes of transport such as bike sharing systems gained even more popularity (Teixeira et al., 2021). Further, cities and governments worldwide invested in cycling infrastructure and policies during the pandemic which further induced largescale increase in micromobility usage (Kraus & Koch, 2021).

The rise of micromobility has provided policymakers with an essential instrument for resolving the first/last mile issue related to public transportation. This is made feasible via intermodality, in which the traveller or commuter uses more than one mode of transportation to get from point A to point B (Goetz, 2009). When using public transportation, a commute is typically regarded as an intermodal trip where the route to or from stops or stations is typically taken on foot. The attractiveness of public transportation reduces in comparison to private modes of transportation when this first or last mile distance is substantial. This is where micromobility comes into play. By offering solutions such as public bike-share systems, especially to access or egress from the public transport stops/stations, the first/last mile problem associated with public transport can be fixed.

Intermodality is key to achieving sustainable urban mobility transitions since the sustainable modes either don't provide door-to-door connectivity or have limited capabilities when it comes to distance (Goetz, 2009). Cities have been working on solutions to improve intermodality through policies and infrastructure development such as mobility hubs. It is important to note that intermodality could also be achieved by combining public transport with other car-centric approaches such as car-sharing, or with other modes such as air, ferry etc(Goetz, 2009). This thesis is centred around intermodality between public transport, especially rail, and micromobility. This is studied from the context of the #ChallengeMyCity project of the EIT Urban Mobility (EITUM) in the cities of Madrid, Milan and Toulouse.

1.1 #ChallengeMyCity Project

#ChallengeMyCity is an EIT Urban Mobility (EITUM) programme that assists European cities in testing innovative and sustainable solutions to solve specific mobility-related problems in their urban environment. These solutions focus on the needs of the cities, complementing their planned political and financial commitments (EITUM, 2021). The #ChallengeMyCity project involves identifying mobility-related issues through public engagement workshops, which are conducted in conjunction with the cities to make sure it fits within their strategic agenda. This is followed by inviting start-ups or other businesses to develop solutions to address these specific challenges that are identified through the workshops.

Once the solutions are in place, a pilot launch event with public participation is done to introduce the initiative to the public and persuade them to try the solutions. The solutions are tested throughout the pilot phase, which can last anywhere between 6 and 12 months. Finally, the data from the pilot phase is collected and the efficacy of the solution is evaluated in terms of its impact. Analysing the impact is necessary for the cities to understand if the solution is feasible, scalable or can be replicated in other areas.

For the year 2022, the program is concentrating on addressing the urban mobility challenges in the cities of Milan, Toulouse, and Madrid. This includes initiatives to enhance intermodal transportation between public transit and micromobility, which is the basis of this thesis. In the case of Milan, Toulouse and Madrid, the challenges are identified in or near major public transportation hubs of Rogoredo, Matabiau, and Chamartín respectively and these are explained in the following sections.

1.1.1 Milan

Milan is Italy's biggest metropolis with an efficient public transport system. Its network of public transport includes the Metro, the commuter rail known as 'ferroviarie suburbane', trams, and buses. The #ChallengeMyCity pilots in Milan will take place in and around the Rogoredo Railway Station in the south of the city. Located outside of the city centre, Rogoredo is considered the gateway to Milan from the South and a crucial interchange node in South Eastern part of Milan.

The Rogoredo station is connected by high-speed rail, interregional, regional and commuter train lines(S1, S2, S12 and S13). Also, it is connected to the Milan metro system with Line 3 and is accessible by bus lines 84,95 and 66. Despite being a significant intermodal hub, it does not offer the fundamental services that an increasing number of commuters require (Azienda Trasporti Milanesi, 2022).

Figure 1: Aerial photo of Rogoredo Station and the surroundings

The city of Milan wants to improve the access to Rogoredo station using micromobility by ensuring effective integration with the existing bike infrastructure of the city and its suburbs. In addition to promoting modal shifts, integration with micromobility has the potential to increase the catchment area of the station, as shown in *Figure 2* below. For achieving intermodality, Milan plans to implement two pilots through the #ChallengeMyCity project:

1. Bike parking for rail commuters in Rogoredo station
2. Safety equipment for bicycle paths to access Rogoredo

By providing safe and secure places to park personal bikes in the station, the first pilot aims to encourage commuters to use micromobility in the first or last mile of the trip. The availability of a convenient bike parking system is predicted to boost the intermodality of commuters who use a mix of rail public transportation and cycling.

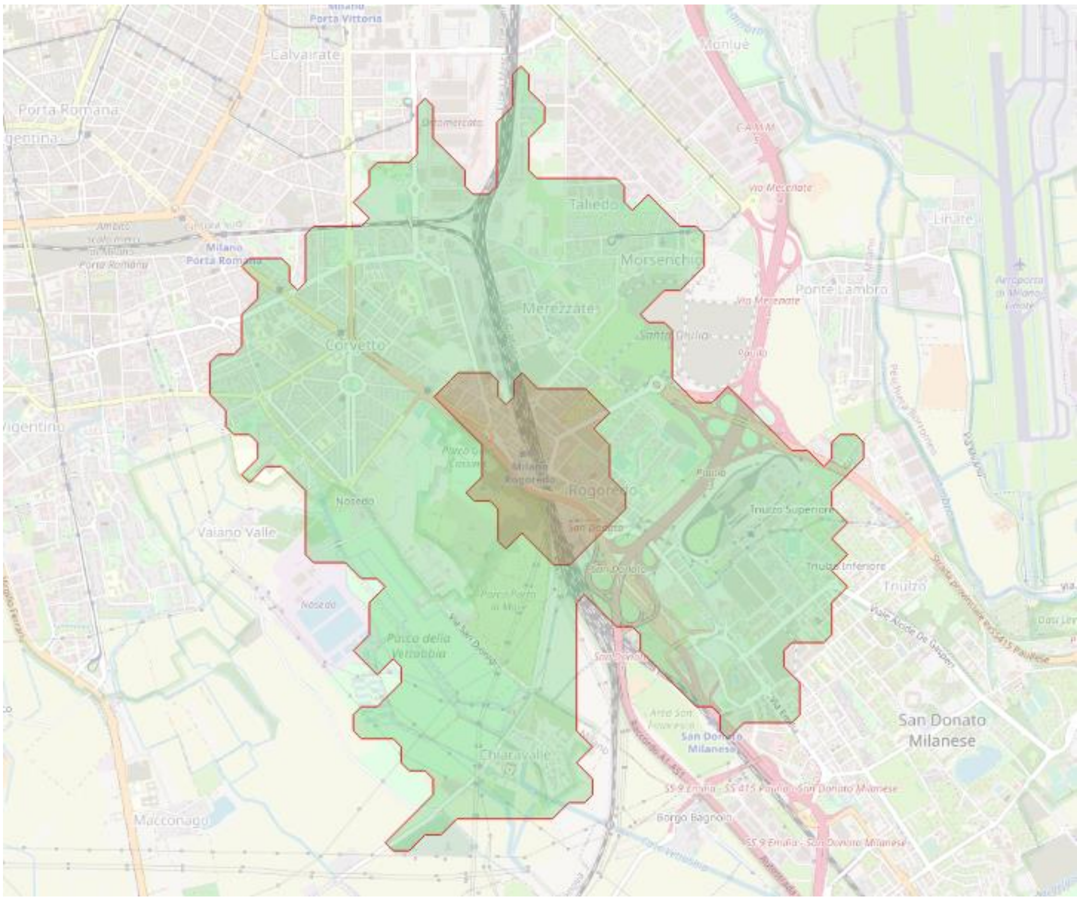

Figure 2: Catchment areas of Rogoredo Station by walking and cycling (10 mins)

Through the second pilot, the city of Milan plans to test innovative solutions to provide increased levels of safety for users. To do this, new signalling equipment is installed, and innovative building methods and materials are used to construct the bike lanes. The idea is to make using micromobility to go to the Rogoredo station safe and low-risk for users. The anticipated effects include increased rider safety when using the bike lane and a decrease in the likelihood of conflicts with other road users.

1.1.2 Toulouse

Toulouse is the 4th largest city in France located in its southern region. It has a public transport network that includes the Metro, tramways and buses for commuting within the city. Toulouse is connected to the national and regional rail network through its main railway station in the heart of the city, Gare Matabiau.

Figure 3: Aerial photo of Matabiau Station and the surroundings

The Matabiau station is the main transport hub of the city, which has connections with French high-speed rail TGV and regional trains (TER) to the rest of France. Also, it is connected to the underground Marengo station nearby, which is part of Line A of the Toulouse metro system. In addition, the station is also accessible by bus line 27 (Tisséo, 2022). Through the #ChallengeMyCity project, the Toulouse Metropole wants to induce a modal shift towards greater use of shared, active and micromobility options within the city. For integrating these mobility options into the available public transport, Toulouse plans to carry out two pilots in Matabiau station as part of the #ChallengeMyCity project:

1. Secured and covered parking facilities for bicycles with recharging facilities
2. Docking station for electric micro-vehicles such as e-scooters

These interventions aim to encourage commuters to use micromobility to access and egress from the Matabiau station, by offering safe and secure spaces to leave personal bikes in the station. It is anticipated that the presence of convenient bike parking or docking stations for the e-scooters will increase the intermodality of commuters who combine riding these micro-vehicles with rail public transportation.

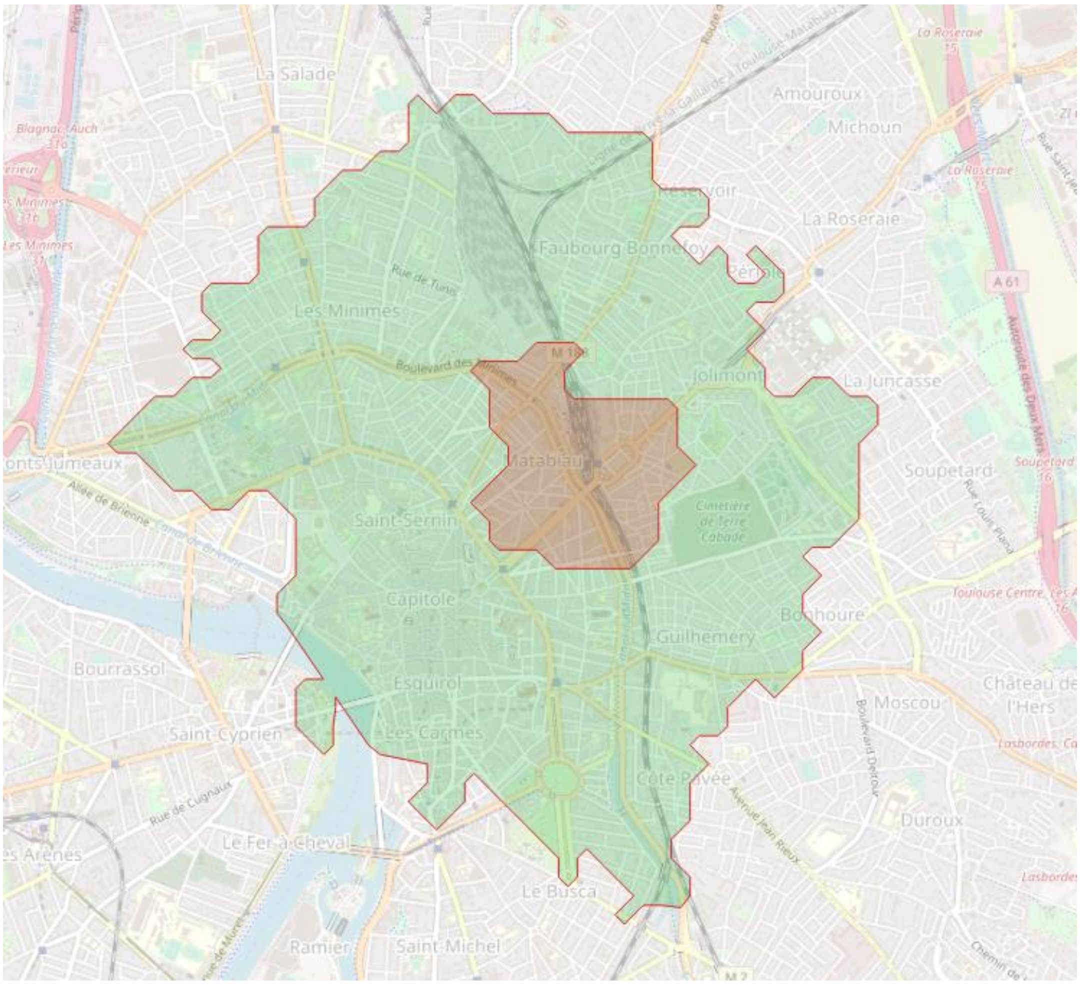

Figure 4: Catchment areas of Matabiau Station by walking and cycling (10 mins)

Like in the case of the Rogoredo station in Milan, micromobility can significantly increase the catchment area of the Matabiau station compared to walking as shown in *Figure 4* above.

1.1.3 Madrid

Madrid, Spain's capital and its largest city, has a well-established and widely used public transport network. The transit system within the metropolitan area of Madrid consists of the Madrid Metro, the commuter rail also known as Cercanías, and the buses. Madrid has two main rail-based mobility hubs that connect it to the rest of Spain and Europe. These are the Atocha station in the south and Chamartín in the North. As part of the #ChallengeMyCity project, interventions are done in the Chamartín station area. Chamartín is a major transport hub in Madrid with connectivity to two metro lines(Line 1 and 10) and 8 commuter rail or Cercanías lines(C1, C2, C3, C3a, C4, C7, C8 and C10). Also, the Spanish high-speed and regional rail networks could be accessed through Chamartín station (Metro Madrid, 2022).

Figure 5: Aerial photo of Chamartín Station and the surroundings

Despite it being an important railway hub in Madrid, Chamartín does not have direct access through a dedicated bike lane. Accessing the station using micromobility from the city centre involves a part of the journey, between Plaza Castilla and the Chamartín station, which has to be done through a segment that doesn't have a safe infrastructure for micromobility users. This is the problem that is addressed as part of the #ChallengeMyCity project. The solutions to be introduced in Madrid as part of the #ChallengeMyCity address the following:

1. Safety for cyclists between Plaza Castilla and Chamartín station installing smart signalling devices and lighting techniques.
2. Monitoring the micromobility flows to enhance safety by installing smart sensors.

These initiatives are important to provide a safe route for the micromobility users to access the Chamartín station. By carrying out these programs, the city of Madrid is trying to facilitate intermodal transport involving micromobility and public transport.

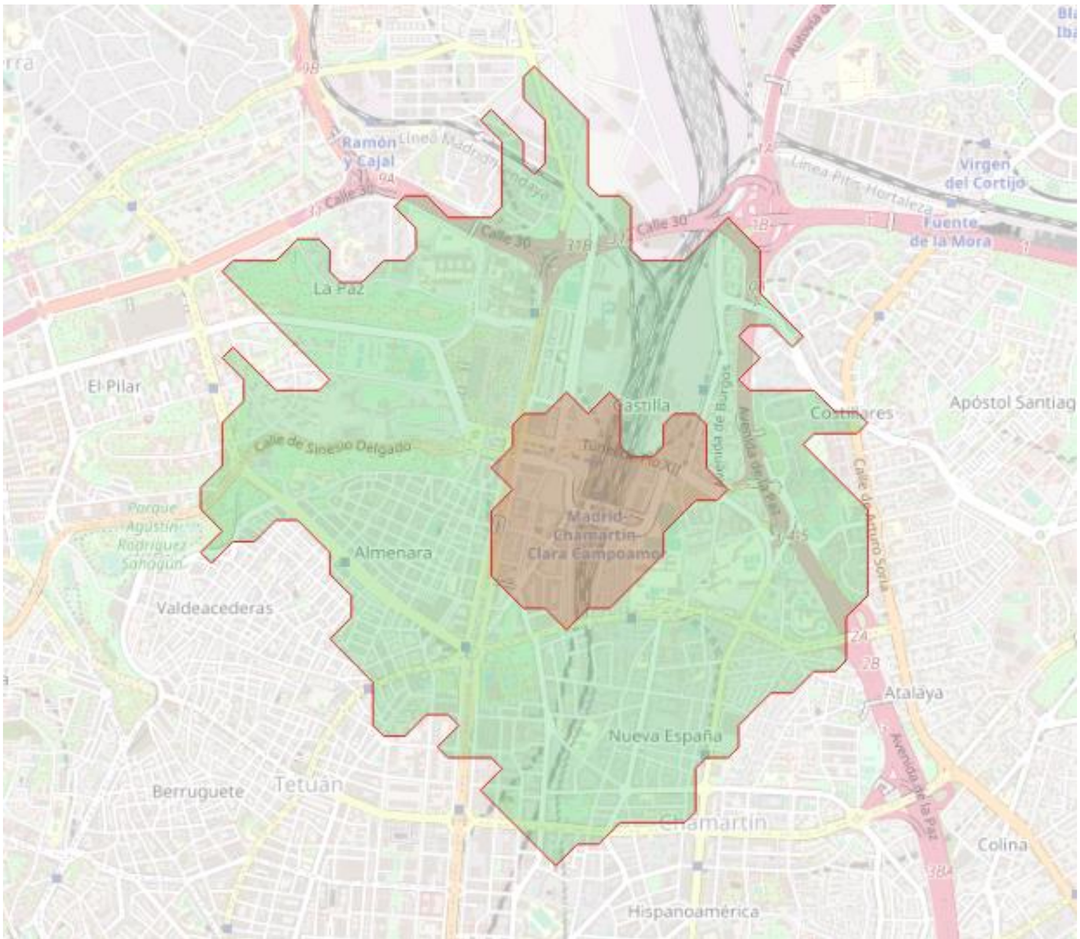

Figure 6: Catchment areas of Chamartín Station by walking and cycling (10 mins)

The solutions which are part of the #ChallengeMyCity project will be implemented from October 2022 in the three cities, and the results of the impact will be collected only in early 2023. Therefore, for this thesis, a previous initiative to support intermodal transportation between a bike-share program and public transport in one of the #ChallengeMyCity project cities is analysed. The bike-share program chosen for this analysis is the BiciMAD in Madrid.

1.2 BiciMAD bike sharing system

BiciMAD is a public bike-sharing program in the city of Madrid operated by Empresa Municipal de Transportes de Madrid (EMT Madrid). It is a station/dock-based bike sharing service that required the bikes to be parked at the docking stations after each use. It began in 2014 with 1560 bicycles and 123 docking stations dispersed around six districts in Madrid (20minutos.es, 2014). Over the years, BiciMAD's network grew to include fifteen of Madrid's districts. It now has 2,964 bicycles and 264 docking stations in its network following its most recent expansion in 2021 (BiciMAD, n.d.).

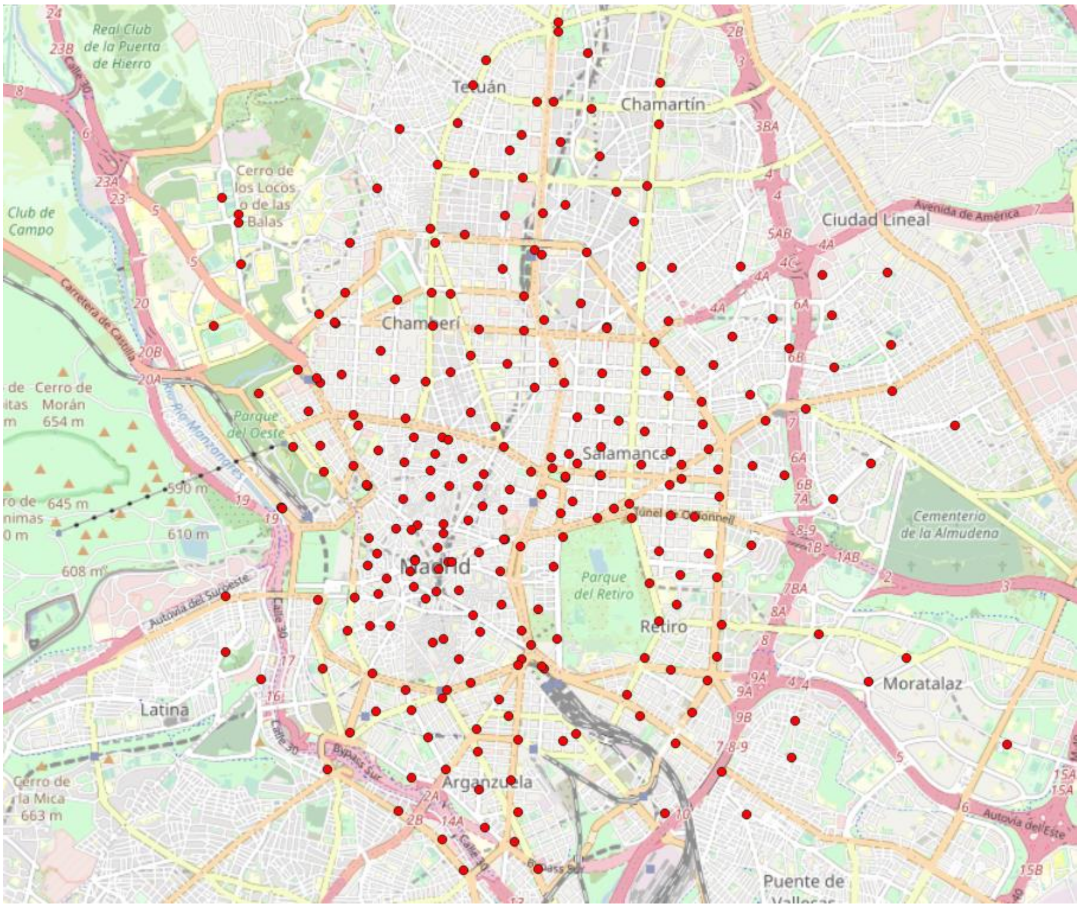

Figure 7: BiciMAD stations in Madrid

As part of its expansion in 2021, BiciMAD added new stations in the Chamartín district in the North of Madrid (Madrid Es Noticia, 2020). This included a new docking station(Station No. 252) installed in front of the Chamartín railway station. An exploratory analysis of station 252 is done in this thesis to examine how the introduction of this particular station led to some patterns of intermodal travel in the area.

1.3 Research Question and Hypothesis

In the context of the #ChallengeMyCity project and a past BiciMAD bike-sharing dock installation in Chamartín railway station in Madrid, this thesis aims to answer the following question related to intermodality between shared micromobility services and public transportation.

- What impact does the availability of micromobility in or near railway stations have on the first/last mile trips and how can we evaluate it?

By answering this question, this thesis will try to verify the hypothesis that the availability of micromobility solutions in or near the railway station promotes intermodal transport involving public transport. Also, it will shed light on how to make use of the spaces present in infrastructure that supports public transportation, such as train stations, to promote shared micromobility for first/last mile trips.

The thesis is structured into the following sections: in section 2, a review of the literature on public transit and micromobility is done with an overview of intermodality and factors enabling it, as well as finding any potential research gaps that need to be addressed; in section 3, the methodology used to analyse the impact of micromobility integration at the Chamartín train station in Madrid is explained; the findings of the analysis are presented in section 4 which is followed by a conclusion, discussing the study's results, limitations and recommendations for future research.

2 Literature Review

In this section, public transport and micromobility are defined along with the different infrastructures that support these modes of transportation. The impact these infrastructures have on the adoption of alternative environmentally friendly means of transportation is also looked at. In addition, a systematic review of published literature on the integration of public transport and micromobility is also investigated. This is done to comprehend the current state of the art in this area and to gain an overview of the lessons learned from various implementations of such multimodal transportation in cities all over the world. The gaps in the literature are also identified in this section.

2.1 Public Transportation

Any mode of transportation that is accessible to the broader public is generally referred to as public transportation. Public transport includes not only the buses and trains that we usually associate it with but also the taxis, as well as air and water-based transport (Preston, 2020). Typically, public transportation refers to land-based modes of transportation like buses and rail networks like the metro, tram, etc. In the past decade, new mobility services for the public had emerged like ride-hailing services like Uber. This makes it difficult to distinctly define what constitutes public transportation. Classification of public transport based on the capacity and operational costs are shown in *Figure 8*. In this thesis, a narrow definition of public transportation is considered that focuses only on buses and trains.

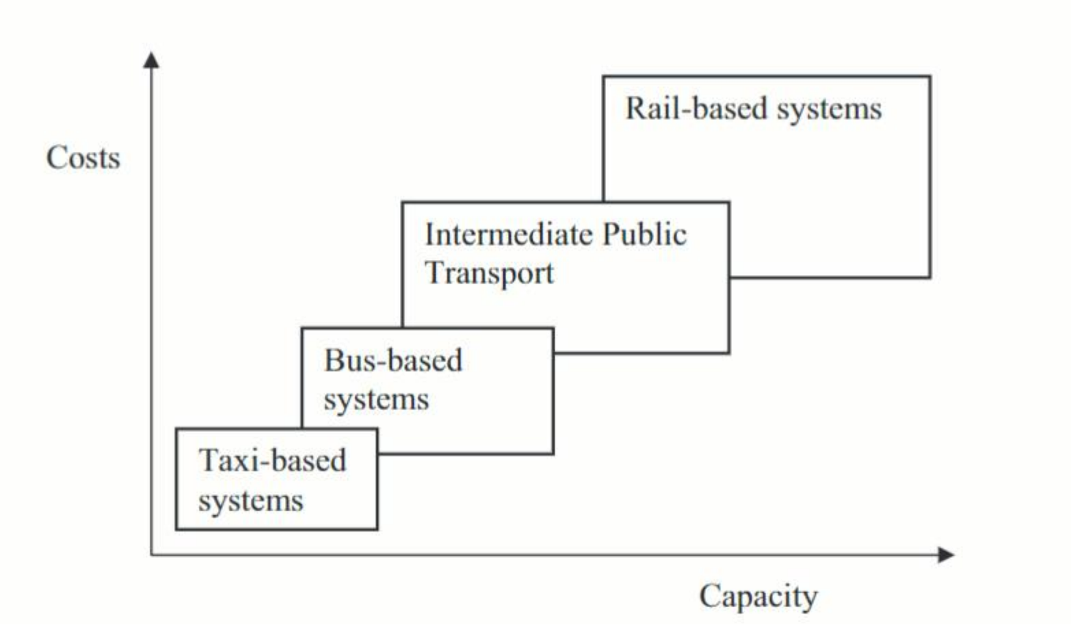

Figure 8: Classification of public transport(Preston, 2020)

2.2 Micromobility

In the context of urban mobility, the term "micromobility" has a somewhat broad definition. These days, micromobility includes a wide variety of micro-vehicles, from bicycles to kick scooters. Although some of them, like bicycles, have been around for decades, the term "micromobility" gained popularity only in recent years. Apart from just describing the vehicles' size, the "micro" in micromobility could also refer to the short-distance trips that could be done using these micro vehicles (Horace Dediu, 2019). This thesis uses the definition of micromobility provided by the International Transportation Forum (ITF), which attempts to define micromobility, based on the vehicle's kinetic energy. As per the ITF report "Safe Micromobility" (ITF, 2020), micromobility is defined as the use of *"vehicles with a mass of no more than 350 kilograms (771 pounds) and a design speed no higher than 45 km/h. This definition limits the vehicle's kinetic energy to 27 kJ, which is one hundred times less than the kinetic energy reached by a compact car at top speed."* The classification of micromobility devices, based on this definition is shown in *Figure 9*.

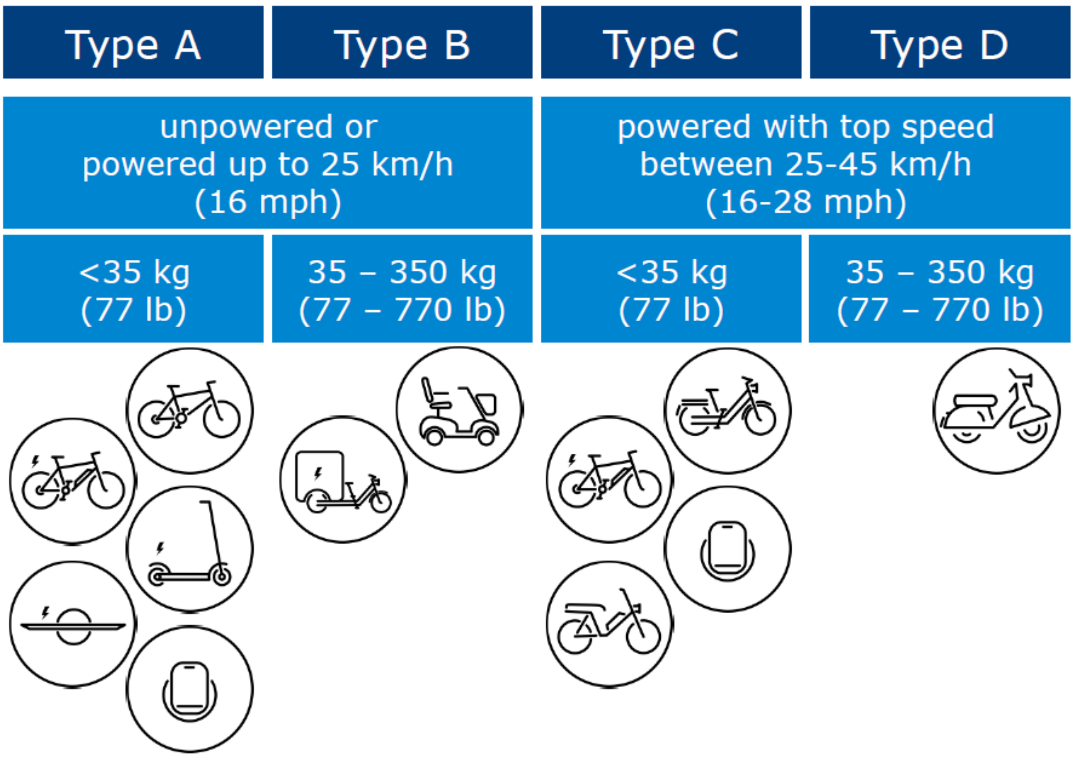

Figure 9: Classification of micromobility(ITF, 2020)

Regardless of the different definitions that exist, micromobility is currently a popular choice of commute in many cities, especially among the younger population. The attractiveness of micromobility is that it offers an on-demand, flexible, and affordable transportation alternative (Shaheen et al., 2020). And for policymakers, it has an important role to play in shaping sustainable urban spaces due to its potential to reduce the usage of private cars for short-distance journeys (Abduljabbar et al., 2021). It is not surprising that the surge in popularity of micromobility followed the realization that private vehicles fueled by fossil fuels emit large amounts of greenhouse gases and clog up space in cities owing to traffic, which lowers the quality of life (Sperling, 2018).

For years, most of the micromobility devices in use were personal bicycles that are pedal-powered. The lithium-ion battery revolution, made possible the development of electric-powered micromobility devices like e-scooters that flood some cities today (ITF, 2020). Additionally, new developments in mobile computing have raised the attractiveness of micromobility as a shared means of transportation (Shaheen & Chan, 2016). People are reconsidering owning cars thanks to the sharing revolution of the last decade where a user pays to use a shared bicycle or any other vehicle (Machado et al., 2018). Shared bike programs have been set up in several cities across the globe during the past few years, and they are widely considered an alternative to private cars for short distances (Fong & Mcdermott, 2019).

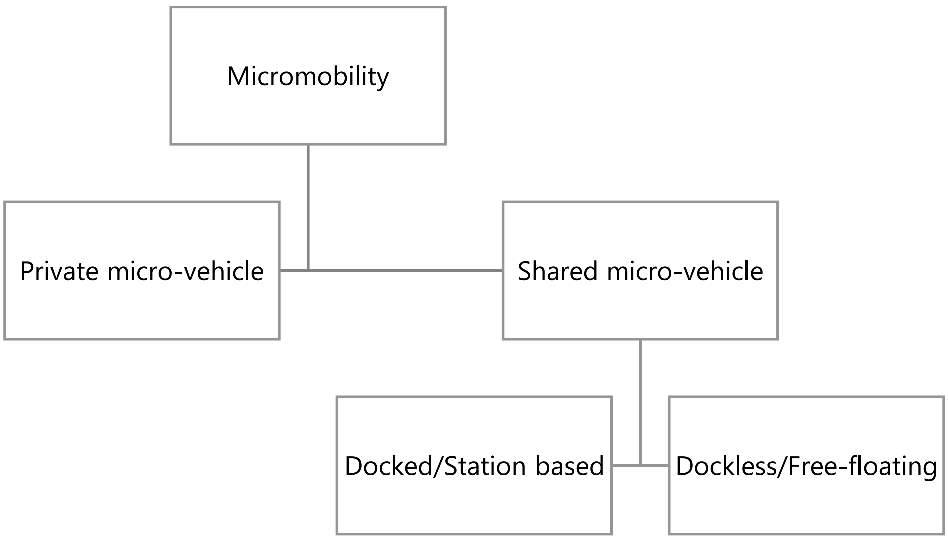

Figure 10: Classification of micromobility based on ownership (Own elaboration)

The two primary categories of shared micromobility systems are docked and dockless. The docked or station-based systems are the ones where the micromobility devices need to be parked in designated parking stations or docks after use. This reduces the flexibility of the sharing systems for the user. Most of the docked systems are public bike-sharing systems operated and maintained by the cities themselves. Dockless sharing systems, also known as free-floating systems overcome the disadvantages of the docked systems by providing micromobility devices to anyone and allowing them to be parked anywhere rather than on designated docks. Even though this provides more flexibility and accessibility, it could cause chaos in the city if not regulated properly.

Shared micromobility plays a crucial role in the current urban mobility ecosystem by supporting the public transport network. It is considered a solution to the first and last mile problem associated with public transportation. This is important because reducing the access and egress distance associated with public transport can help increase the geographical coverage of the whole system, making it available to a larger population (Fearnley et al., 2020). Also, this could help in making public transport compete against private cars which always had the advantage when it comes to convenience. In addition to supporting public transport, micromobility in itself stands to benefit due to its integration with public transport. One study conducted in Oslo found that users may use scooters more often if there is better integration with public transport (Fearnley et al., 2020).

2.3 Public transport and micromobility integration

Integrating micromobility with public transportation plays a significant role in facilitating sustainable urban mobility transitions in our cities (POLIS, 2019). Understanding how micromobility helps in solving the Achilles heel of public transportation, which is first and last-mile travel has the potential to speed up the transition to sustainable urban transport systems. Solving the first/last mile problem associated with public transport, can improve access to services and opportunities, also contributing to changes in mobility behaviours among the population to move towards a less car-centric society (Thomas Holm Møller & John Simlett, 2020). As a result, it is necessary to view micromobility and public transport as two essential aspects of the same interconnected system.

When micromobility and public transportation are combined and viewed as a single trip chain, as a 'hybrid, distinct transport mode (Kager et al., 2016), they can be considered a sustainable mode of transportation where the benefits of each can complement one another. The strengths of micromobility, being flexible and offering door-to-door accessibility could complement well with the spatial reach and mass transportation characteristics of public transport. This synergy of higher speeds, greater spatial reach, and door-to-door accessibility can make this combination of micromobility and public transport compete against private motorised transport such as a car (Kager et al., 2016). It has the potential to initiate modal shifts which in turn could lead to a more sustainable and liveable society.

2.3.1 System characteristics

The integration of micromobility and public transportation can be done in different ways, and it depends on the infrastructure and type of services available (Oeschger et al., 2020). As was previously discussed, there are two types of micromobility: private and shared, with the latter category further subdivided into station-based and dockless sharing systems. Depending upon the type of micromobility vehicle, the infrastructure and services required for integration with public transport vary. For example, if the micromobility device is privately owned and needs to be combined with a public transport journey, normally a storage facility would be required at the public transport stations. Whereas in the case of shared micro-vehicles, the public transport station ideally should have docking stations with available space or have areas reserved for parking free-floating micromobility. The different infrastructure and services which are required for various micromobility systems in the first mile and last mile of the intermodal trips are shown in *Table 1* and *Table 2* respectively.

Table 1: Required infrastructure and services at the first mile – from origin to PT station (Oeschger et al., 2020)

Mode	Infrastructure/Service	
	at Origin	at PT Station
Private micromobility	1. Safe and convenient storage space	1. Safe, convenient, affordable storage space 2. Segregated pedestrian infrastructure to access the PT station
Shared micromobility - from the docking station	1. Availability of micromobility sharing station in the proximity of trip origin 2. Availability of micromobility devices at the time of departure	1. Availability of micromobility sharing station in the proximity of PT station 2. Availability of free spaces/docks 3. Segregated pedestrian infrastructure to access the PT station
Shared micromobility - free-floating/dockless	1. Availability of micromobility devices in the proximity of trip origin at the time of departure	1. Availability of space/designated area to end the trip in the proximity of the PT station 2. Segregated pedestrian infrastructure to access the PT station

Table 2: Required infrastructure and services at the last mile – from PT station to destination (Oeschger et al., 2020)

Mode	Infrastructure/Service	
	at PT Station	at Destination
Private micromobility	1. Safe and convenient storage space	1. Safe, convenient, affordable storage space 2. Segregated pedestrian infrastructure to reach the destination
Shared micromobility - from the docking station	1. Availability of micromobility sharing station in the proximity of PT station 2. Availability of micromobility devices at the time of departure	1. Availability of micromobility sharing station in the proximity of destination 2. Availability of free spaces/docks 3. Segregated pedestrian infrastructure to reach the destination
Shared micromobility - free-floating/dockless	1. Availability of micromobility devices in the proximity of PT station at the time of departure	1. Availability of space/designated area to end the trip in the proximity of the destination 2. Segregated pedestrian infrastructure to reach the destination

When a single trip chain, consisting of micromobility and public transport is considered, the micromobility alternatives in *Table 1* and *Table 2* can be used in a variety of ways depending on the infrastructure and services available at the origin, public transport station, or destination. For instance, a person can use their micro-vehicle from the origin in the first mile and store it in the PT station. They can then take public transport to arrive at the PT station in the destination area and could continue the last mile of the journey using a shared micro-vehicle available in the docking station in the proximity of the PT station. This trip chain is shown in *Figure 11* below.

Figure 11: An intermodal trip chain involving personal and shared micromobility (Own elaboration)

It is important to note that *Table 1* and *Table 2* mention only the services and infrastructure required for different types of micromobility in the first and last mile of the journey. The trip journey that combines public transport and micromobility often involves a part of it, either in the first mile or the last mile, done by walking. In that case, it is necessary to have a safe and segregated pedestrian infrastructure to either access/egress from the PT station (Oeschger et al., 2020). Also, another way of integrating private micromobility with public transport is when the micro-vehicles are taken on board the transit. In this case, the same micro-vehicle could be used for the first and last mile of the journey. For this type of integration, the public transport vehicle and platforms must be easily accessible. Additionally, the public transport vehicle should have enough space inside to accommodate the micro-vehicle. Instead of using traditional bikes, which are bulky and take up too much space, this form of integration is more convenient when using small, lightweight micro-vehicles, such as kick scooters or foldable bicycles.

2.3.2 Infrastructure

One of the important interventions required to facilitate the integration of micromobility and public transport is providing dedicated bike lanes for micro-vehicles that are protected from motorised vehicular traffic. A safe, comfortable and extensive network of bike lanes is essential not only for integration with public transport but also to encourage the use of micromobility among the population. Therefore, cities and governments need to provide the necessary micromobility infrastructure like bike lanes to speed up the transition to sustainable modes of transport (Grosshuesch, 2020).

Improving the road conditions, like avoiding intersections along the route of a bike lane can help reduce the risk of an encounter with other road users, which in turn can help in enhancing the experience of micromobility users (Guo & He, 2020). The use of traffic calming measures and regulations near the public transport stations can help in controlling motorised traffic as well as in providing safe and quick access for micromobility users to public transport (Böcker et al., 2020).

As was already established, a key element in evaluating the effectiveness of integration is the accessibility of affordable, convenient, and safe parking options in the public transportation hubs (Adnan et al., 2019). This is of importance for commuters with personal micro-vehicles who access the public transport station since unsafe parking spaces could lead to the theft of the micro-vehicles, which can prevent the users from using their micro-vehicles in the first or last mile of the trip (de Souza et al., 2017).

In the case of shared micromobility, both station-based and free-floating, the main issue is in ending the trip near the proximity of a public transport station when there are no free spaces available in the docking station or the designated parking areas. This can deter the users from using micromobility to access or egress from the station. Therefore, the availability of both shared bikes, as well as free docks in the vicinity of the station is important (Ji et al., 2017). Also, in a study conducted in Oslo, it has been found that the maximum distance the users were willing to walk to a docking station/parking space nearby the public transport station is 200 m (Böcker et al., 2020).

Another recommendation from the literature is to reduce the number of car parking spaces in public transport stations to induce modal shifts, from private cars to micromobility, while accessing public transport (Midenet et al., 2018). The number of car parking spaces available in the station can negatively affect the usage of micromobility to access the stations (Chan & Farber, 2020). Also, it is suggested that investing in bike-and-ride facilities at the stations is a more sustainable option, and also results in the efficient use of available space compared to park-and-ride facilities (Pucher & Buehler, 2009).

Implementation of public bike-sharing programs and increasing their availability have a significant role in promoting cycling, which in turn has an impact on the bicycle or car use to access or egress from public transport (Zhao & Li, 2017). Further, planning shared micromobility services, specifically to act as complementary to public transport can promote modal shifts from private cars (Tavassoli & Tamannaei, 2020). Expanding the shared micromobility programs into the suburbs and providing docking stations or bikes near schools, offices or residential areas could also encourage commuters to use micromobility in combination with public transport (Ma, Ji, Jin, et al., 2018).

2.3.3 Built Environment

The use of micromobility in the first or last mile trips is affected by the built environment around the public transport stations. Since the built environment cannot be easily changed in existing cities, it is crucial to support multimodal transportation that includes public transportation and micromobility in future land projects. A recommended course of action is to encourage dense, connected communities with mixed land use, as well as a pedestrian- and bicycle-friendly neighbourhoods (Sagaris et al., 2017a). Non-residential land-use types such as offices, commerce, and education near the stations can promote micromobility usage for access and egress (Rietveld, 2000).

The network characteristics of the street, like the number of intersections, and that of the transit system, affect the distance that could be accessed or egressed using micro-vehicle (Hochmair, 2015). Also, it has been found that the mode choice for the access and egress trips to and from the public transport station is significantly influenced by the presence of greenery along the bike path that provides natural shade (Y. H. Cheng & Liu, 2012). These factors are also important when it comes to finding optimal locations for the micromobility-sharing stations (Guo & He, 2020).

2.3.4 Technology

To facilitate the integration of micromobility and public transport, technology has a crucial role to play. Real-time availability of data and mobile applications are necessary to provide a user-friendly service for shared micromobility systems. Real-time information on the usage and the availability of micro-vehicles at the docking stations can help commuters to plan well in advance. This data is also important for the operators to optimise the redistribution of micro-vehicles based on demand (Yang et al., 2019).

Redistribution of micro-vehicles, adapting to the changes, is one of the main factors for the successful integration of micromobility with public transport because it determines the availability of vehicles for the commuters at access and egress (Guo & He, 2020). And in commutes where the micromobility devices are taken aboard public transport, information on available spaces in the carriages should be provided in real-time (Bachand-Marleau et al., 2011).

Technology also has a role to play in ensuring the quality as well as monitoring the maintenance requirements of the vehicles (Fan et al., 2019). Safety and user satisfaction can ultimately attract new users into the system. Also, adapting the shared micromobility systems to the special needs of various user groups and trip purposes can reduce the inequalities a help more people use micromobility along with public transport (Y. H. Cheng & Liu, 2012).

2.3.5 Planning

When micromobility and public transport are considered as part of one single transport system and developed accordingly, it can help in improving the integration between these two modes (Kager et al., 2016). The public bike-share systems, for example, should be planned in such a way that it supports the public transport network, helping in increasing its reach. Such participatory planning, involving users and local communities from the early stages can help in developing an efficient intermodal system that benefits everyone (Sagaris et al., 2017b).

To establish common objectives and make progress toward them, the local administration and the micromobility providers should work closely together from the start of the planning process (Griffin & Sener, 2016). Successful implementation of shared micromobility services can also be guaranteed by yearly assessments and performance evaluations that involve the public (Griffin & Sener, 2016).

When compared to walking, the transit access distance is tripled in the case of micromobility. This aids in enhancing low-income user groups' access to opportunities and services via transit (Zuo et al., 2020). Also, it has been established that bike-based transit-oriented development (TOD) can expand the catchment areas of public transit compared to conventional transit-oriented development (TOD) based on walking (Lee et al., 2016). Therefore, it is necessary to ensure that micromobility-friendly environments are part of the urban mobility master plans. In addition to having the financing set aside for integration with public transit, the cycling master plans should also include details related to integration (Weliwitiya et al., 2019).

To prioritize allocating resources to areas with low levels of access to services and opportunities by public transportation, evaluations of transportation investment proposals and policies should take equity and social inclusion into consideration (Hamidi et al., 2019). Further, it has been suggested that prioritising initiatives to improve the micromobility systems in areas with high latent demand, can have a significant impact on modal shifts towards micromobility in those areas (Chan & Farber, 2020).

2.3.6 Policies and regulations

The user experience, safety, and willingness to embrace the mobility practice of merging micromobility and transit are influenced by policies and laws. This is especially important when it comes to new micro-vehicles like e-scooters, which are clogging up the streets of many cities and forcing authorities to severely restrict or outright ban them (Grosshuesch, 2020). One method of promoting and regulating new micromobility is to refer to the laws already in place for human-powered micro-vehicles like bicycles and adapt them to the new micro-vehicles like e-scooters or dockless bike-sharing systems.

Introducing fines to comply with regulations is an effective way to manage the chaos caused by micromobility (Grosshuesch, 2020). Illegal parking on bike lanes or near the infrastructure around public transportation should be penalised since this may affect the transit-bike-share integration experience (Ji et al., 2018). Exclusive road space and rights for micromobility users should be part of the transport policies to enhance the adoption of micromobility and its integration with public transit (Zhao & Li, 2017).

To reduce conflicts with other road users, it is recommended to prioritise micromobility users at intersections as it can help in improving visibility and safety (Fan et al., 2019). Also, limiting the vehicle speed on roads adjacent to or nearby the transit stations can improve safety and overall user experience (Weliwitiya et al., 2019). Finally, in addition to the initiatives supporting transit-micromobility integration, policies that restrict the ownership or purchase of a second car can induce modal shifts away from private cars at least in a short term (Liu et al., 2020).

2.3.7 Pricing and Incentives

Pricing, incentives and discounts are important instruments to boost micromobility and public transport integration. Integrated ticketing systems for public transit and micromobility can enhance the user experience as well as make the transfer between the modes more efficient (Böcker et al., 2020). This can also be a tool to understand the mobility patterns and behaviours of the user, which could in turn be used to make improvements in the system.

A flexible pricing system, with reduced prices for non-peak hours, is an effective instrument to evenly spread the demand throughout the day. Additionally, it has been suggested that the duration of any free micromobility rentals be restricted to between 30 min and one hour (Ma, Ji, Yang, et al., 2018). Offering incentives for longer sharing trips can help in expanding the catchment area of the public transport stations (Lin et al., 2019). To keep the fares low, the government has to provide subsidies and incentives. This is important to ensure equitable access to micromobility and public transport for disadvantaged populations (Zuo et al., 2020).

Offering discounts for intermodal trips is suggested as an important measure to attract new users (Ji et al., 2018). And for frequent users, introducing a loyalty program could be beneficial (Y. H. Cheng & Liu, 2012). Rental limitations such as the maximum rental duration should be lifted to help women and other disadvantaged user groups. Also, the administration can provide incentives to bike-sharing operators to set up infrastructure and services in low-income neighbourhoods (Böcker et al., 2020). Finally, the government can offer a tax rebate to companies that support their employees to use micromobility and public transport (de Souza et al., 2017).

2.3.8 Training and educational campaigns

Training and educational campaigns are essential tools to raise awareness and promote intermodal transport between micromobility and public transit. This is important since the provision of necessary infrastructure alone cannot ensure equitable access to services among the population as there are other barriers, like poor cycling skills, which could deter potential users (Hamidi et al., 2019). Also, many of the new micromobility-sharing systems available aren't inclusive of the elderly population since they rely heavily on technology. Public education campaigns and social marketing specifically targeted at the elderly population can help in overcoming this barrier (Ji et al., 2017). Among the younger users, promoting micromobility is important since it has been found that they use micromobility or public transport due to economic reasons, and may end up abandoning them if they can afford other alternative modes (Liu et al., 2020). Additionally, creating awareness about the negative impacts of motorised vehicles on the environment is suggested as a method to encourage a modal shift away from cars (Y. H. Cheng & Liu, 2012).

2.4 Findings and Research Gap

As described in the previous sections, it is evident that prior studies on the integration of public transportation and micromobility had mostly concentrated on elements that could facilitate seamless integration. These elements can be classified broadly into two categories, which are:

1. System characteristics, like the built environment, amenities at public transport stations, infrastructure for micromobility etc. These can influence people to use micromobility to access public transport.
2. User characteristics such as socio-demographic features, preferences, mobility patterns, etc. Understanding the factors that can influence the mode choice of the user is pivotal, since certain users may have barriers preventing them from using micromobility to access transit.

The studies have not attempted to ascertain the impacts of combining micromobility with public transportation. Although several of the papers did discuss the advantages of integrating micromobility and public transportation, quantification of the impacts was done only in a few of them (Y.-H. Cheng & Lin, 2018; Krizek & Stonebraker, 2011; Li et al., 2020). This has been identified as a research gap in this literature review. Studying the impact of integration between micromobility and public transport is crucial because:

1. It offers proof of impact to provide a compelling case for the development of new integrated transport systems as well as for improving existing implementations.
2. It helps in determining different causalities, reducing the adverse effects and also enhancing positive outcomes.
3. Quantification of the impact of integration on society, such as access to services and opportunities for different population groups, can help in giving priority to initiatives that promote social inclusion.

In the following sections, an analysis of the previous installation of a micromobility docking station near a major public transport hub in Madrid is done to study its impact on intermodal transport. The analysis is carried out to test the research hypothesis that the introduction of micromobility solutions in or near a public transport hub such as a railway station, promotes intermodality involving public transport.

3 Methodology

This section describes the methods used to analyse the impacts of introducing a docking station (Station 252 of BiciMAD) for micromobility in a public transport hub (Chamartín railway station). The methodology defined here is expected to be used for quantifying the impact of various implementations which will be done as part of the #ChallengeMyCity project in late 2022.

3.1 Data Collection

The data collection consisted of two steps. Firstly, it involved choosing the BiciMAD stations of interest nearby Chamartín station for the analysis. This was done by creating a travel time map or isochrones for different walking times from the Chamartín station. A geographic information system(GIS) software, QGIS was used for this purpose, with an additional plugin (*Travel Time*, n.d.) to create the isochrones. The isochrone map is shown in *Figure 12* below.

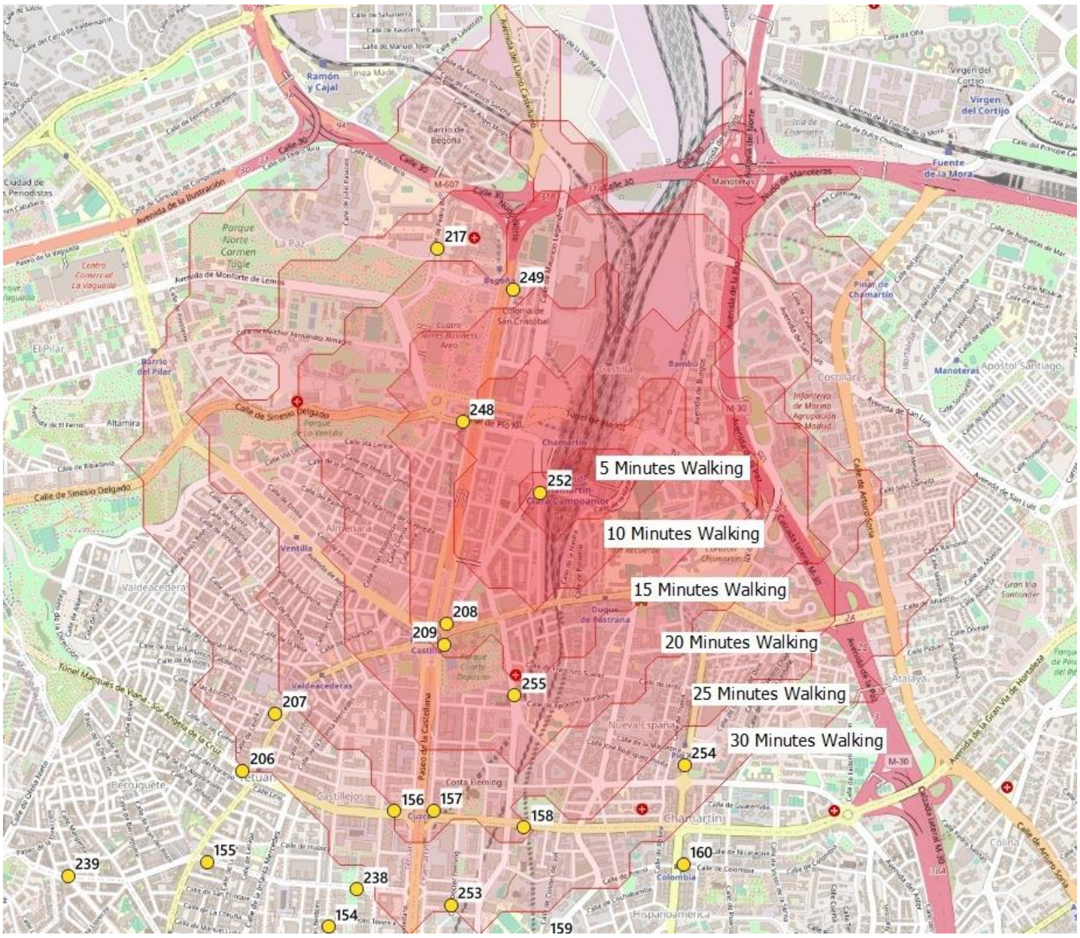

Figure 12: Isochrone map of the catchment area of Chamartín Railway Station

In all, twelve BiciMAD stations that fell within 30 minutes of walking from Chamartín were selected for the study, as shown in *Table 3*.

Table 3: BiciMAD stations within the catchment area of Chamartín Railway Station

Station	Date of Inception	Walking Distance from Chamartín Station					
		5 mins	10 mins	15 mins	20 mins	25 mins	30 mins
156	05/03/2015						Yes
157	05/03/2015					Yes	Yes
158	05/03/2015					Yes	Yes
207	20/06/2019						Yes
208	04/09/2019			Yes	Yes	Yes	Yes
209	16/10/2019			Yes	Yes	Yes	Yes
217	11/09/2019					Yes	Yes
248	29/12/2020			Yes	Yes	Yes	Yes
249	29/12/2020				Yes	Yes	Yes
252	29/12/2020	Yes	Yes	Yes	Yes	Yes	Yes
253	29/12/2020						Yes
254	29/12/2020						Yes

The closest BiciMAD stations to the Chamartín rail station used to be stations 156 and 157, which were 1.6–1.8 kilometres on foot. Two new BiciMAD stations, 208 and 209, opened in September 2019 and were 0.8–1.0 kilometres from Chamartín station. Finally, station 252 was opened in December 2020 right outside the railway station (Madrid City Council, 2015, 2020).

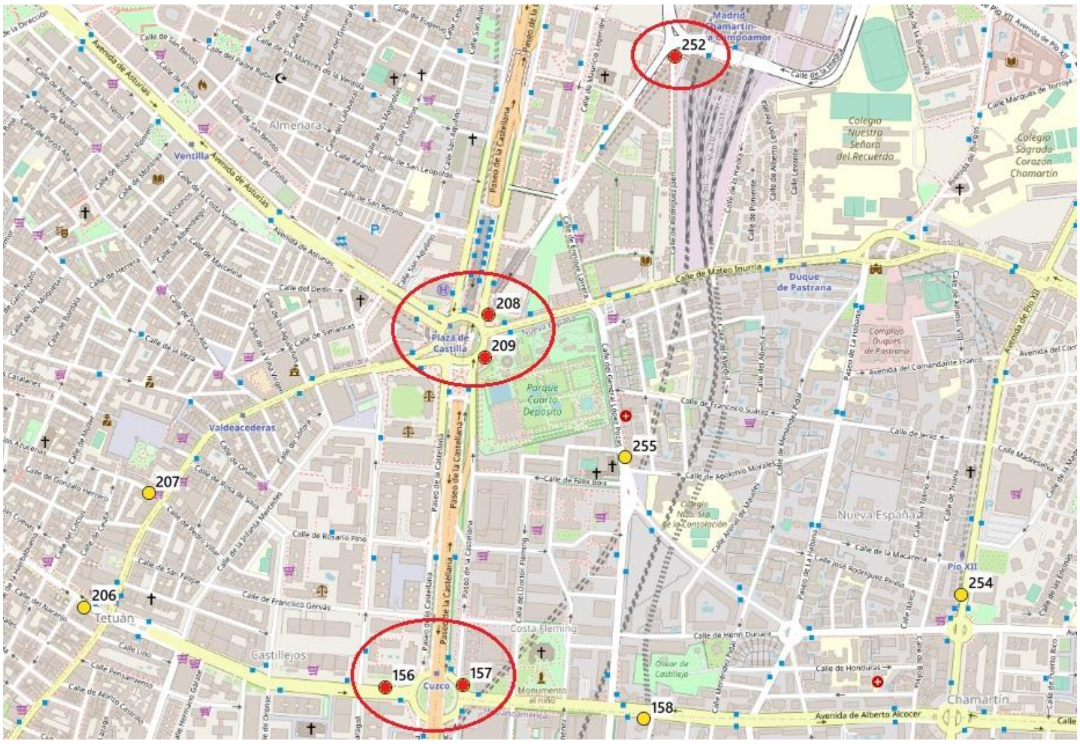

Figure 13: Nearest BiciMAD stations by foot to Chamartín Railway Station

Up until December 2020, when BiciMAD station 252 came into existence, stations 208 and 209 in Plaza Castilla were the closest BiciMAD stations to Chamartín railway station. Therefore, before December 2020, there was a 0.8–1.0 kilometres distance that had to be completed on foot to get from Plaza Castilla to Chamartín railway station or the other way for intermodal trips utilizing BiciMAD and trains from Chamartín station. An example of one such intermodal trip is explained in *Figure 14*.

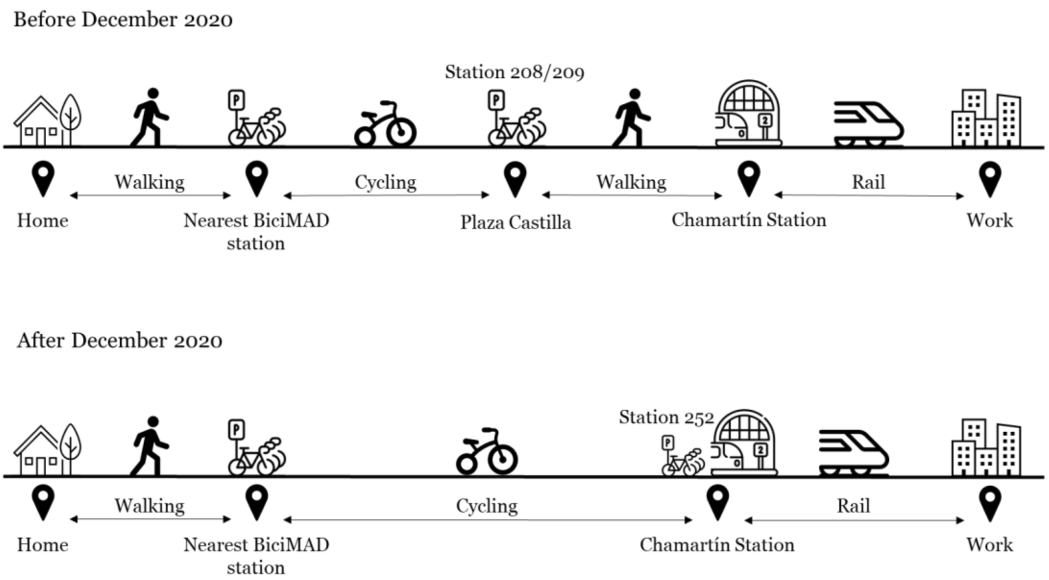

Figure 14: An example of an intermodal trip chain in the first mile involving BiciMAD and a train from Chamartín railway station (Own elaboration)

In the second step after data collection, the ride usage data for the twelve selected BiciMAD stations near the Chamartín station were obtained from the open data website of EMT Madrid(https://opendata.emtmadrid.es/Home). The website had data for every month beginning from April 2017 to June 2021 (EMT Madrid, n.d.). The period of study chosen for this thesis is from January 2019 to June 2021. The data from EMT Madrid's open data had timestamp information of the trips in JSON file format which needed to be processed in Python and converted to excel spreadsheets(.csv format) for the analysis. The python script used to generate the .csv files was obtained from an open source code and attached in Annexure I (Javi Ramírez, 2017).

Two types of data were extracted from the JSON files, which related to trips either originating or ending in the BiciMAD stations within a 30 minutes walking distance from Chamartín railway station. The trips were categorised as first mile or last mile trips depending on whether they started or ended in any of the BiciMAD stations within the 30 minutes walking catchment area.

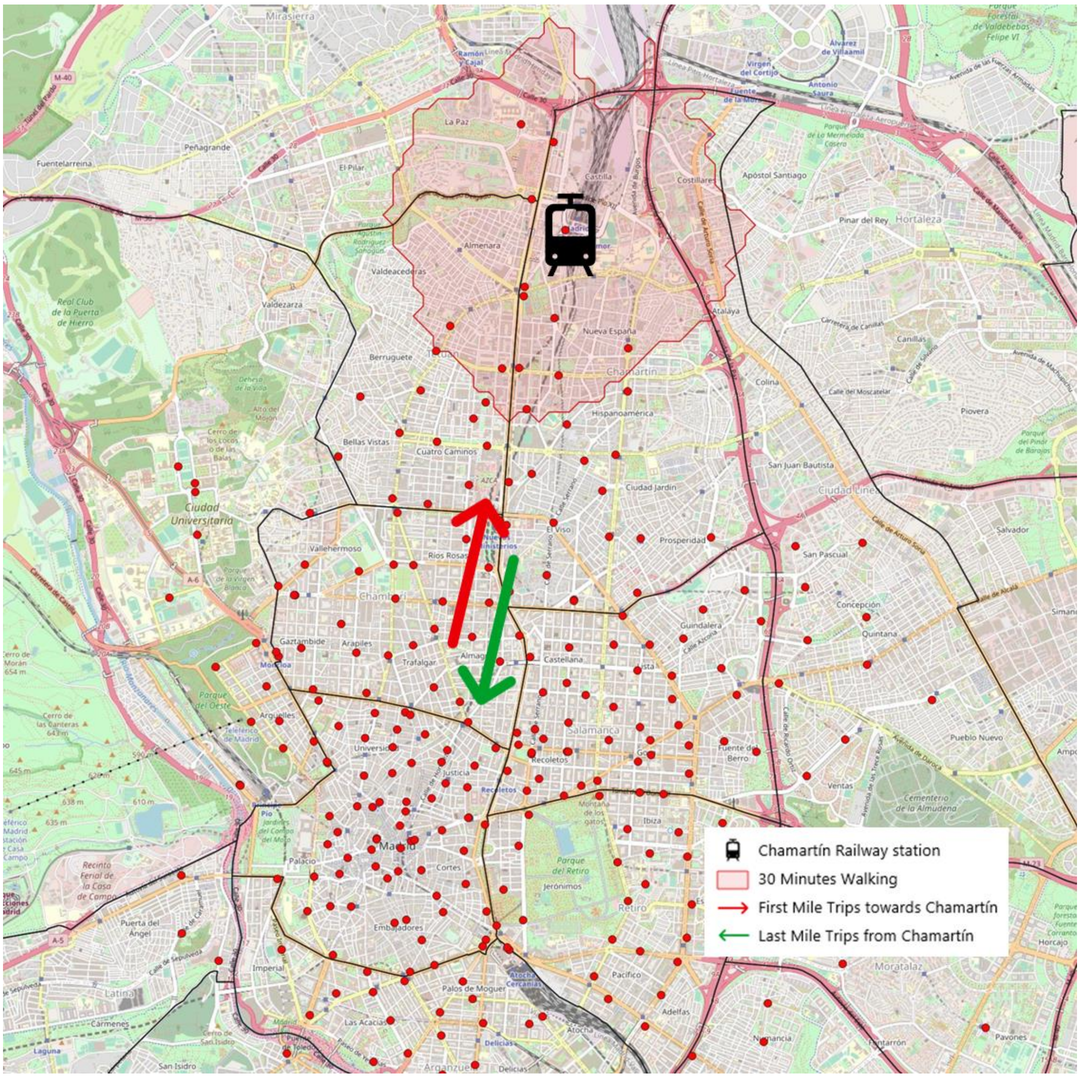

Figure 15: Categorisation of first mile or last mile trips (Own elaboration)

In total, 430 excel files were created from the JSON files available on the EMT Madrid open data portal for the 12 BiciMAD stations under consideration. It has the details of 602,222 individual BiciMAD trips between January 2019 and June 2021, of which 298,689 trips ended near the 30-min catchment area of Chamartín station (first mile) and 303,533 started near it (last mile). The details of data obtained for the twelve BiciMAD stations are described in *Table 4*.

Table 4: Details of data obtained for each station

Station	Data Used		Days
	From	To	
156	01/01/2019	30/06/2021	912
157	01/01/2019	30/06/2021	912

Station	Data Used		Days
	From	To	
158	01/01/2019	30/06/2021	912
207	20/06/2019	30/06/2021	742
208	04/09/2019	30/06/2021	666
209	16/10/2019	30/06/2021	624
217	11/09/2019	30/06/2021	659
248	29/12/2020	30/06/2021	184
249	29/12/2020	30/06/2021	184
252	29/12/2020	30/06/2021	184
253	29/12/2020	30/06/2021	184
254	29/12/2020	30/06/2021	184

In addition to BiciMAD trip information, a list of stations which were in operation during the study period was also obtained from the open data website. A total of 269 BiciMAD stations were in existence during this period. The list included information such as the address, GIS coordinates, latitude, longitude, district, barrio (neighbourhood), and the number of docking bases at the station. The stations were spread across 60 barrios belonging to 15 districts of Madrid. These data were used for visualising the stations and trip analysis in the QGIS software.

3.2 Data Pre-processing

The BiciMAD trip dataset obtained from the EMT Madrid website had different fields which are described in *Table 5*. For the analysis, 'idunplug_station', 'idplug_station', 'unplug_hourTime', ' travel_time' and 'user_type' columns were only used.

Table 5: BiciMAD dataset description (EMT Madrid, 2016)

Field name	Description
_id	Trip identification details
user_day_code	User identification details for a day
idunplug_station	The station from which the trip has originated
idunplug_base	The dock in the origin station from where the bike was unplugged
idplug_station	The station where the trip has ended

Field name	Description
idplug_base	The dock in the destination station where the bike was parked
unplug_hourTime	The hour at which the trip had started. Minutes and seconds are not available to maintain anonymity
travel_time	Length of the trip in seconds
track	Travel details in GeoJSON format.
user_type	0: undetermined; 1: annual pass; 2: occasional user; 3: BiciMad employee
ageRange	0: undetermined; 1: [0..16]; 2: [17..18]; 3: [19..26]; 4: [27..40]; 5: [41..65] 6: [>66]
zip_code	User's postal code.

Some data cleaning measures were done before the analysis to remove anomalies in the data. These measures are described below:

1. Trips originating and ending in the same BiciMAD stations were not considered for the analysis.
2. Trips which are longer than 7200 seconds or 2 hours were filtered out, along with those that have negative travel times.
3. Only the trips done by annual pass holders or regular users were considered for the analysis. All the other trips that include occasional users and BiciMAD employees were removed.
4. Since the list of stations obtained from the open data portal did not contain any information about stations 64,66, 262, 263, 264, 265, 267, 268, 269 and 270 during the study period under consideration, trips beginning or ending at these BiciMAD stations were removed from the extracted data.
5. All trips that were recorded between March 2020 to June 2020 are removed to negate the effect of Covid-19 lockdowns which were in place in Spain during that time (el Pais, 2020; The Guardian, 2020).
6. The week of January 7–15, 2021, was excluded from the analysis since Madrid experienced a once-in-a-century snowstorm ‘Filomena’ at that time (BBC, 2021).
7. Since there were no trip data available for Station 255 located in the Chamartín district from the EMT Madrid portal, this BiciMAD station was not taken into consideration for the analysis.
8. Some BiciMAD stations that are close to each other are identified by the letters ‘a’ or ‘b’ along with the station number. Such stations are considered as one and identified with their station number. For example, 25a and 25b are considered as one BiciMAD station 25.

The number of BiciMAD trips for analysis had decreased after pre-processing from 602,222 trips to 519,514 trips. This included 247,924 first-mile trips ending near Chamartín station and 271,590 last-mile trips near it between January 2019 and June 2021.

3.3 Data Analysis

After pre-processing, the information from the list of stations was used to assign each trip the origin district and barrio for the unplug station (first-mile trip), and the destination district and barrio for the plug station (last-mile trip). The trips were then separated for weekdays and weekends for both first mile and last mile trips and the analysis was done separately for each of them. There were 412,372 trips on weekdays (196,964 first-mile, 215,408 last-mile) and 107,141 trips on weekends (50,960 first-mile, 56,181 last-mile).

To see the temporal variance of the first-mile and last-mile trips from the 12 BiciMAD stations nearby Chamartín railway station, the trips were categorized according to the time of day, and an hourly average of trips beginning or finishing in these stations was calculated. Also, this was visualised in a chart to determine the peak period in each of these BiciMAD stations. All these steps were done separately for trips that happened on weekdays and weekends.

Further, to obtain the spatial dynamics of the first or last-mile trips, a matrix was created to determine the hourly average number of trips between the twelve BiciMAD stations nearby Chamartín railway station and the different districts and barrios within Madrid. This matrix was used to visualise the spatial characteristics of the trips in QGIS software. Also, another matrix was created to determine the average hourly trips between the selected 12 BiciMAD stations and the rest of the stations in the BiciMAD network. This was done to identify the most popular routes.

Additionally, a micro-level analysis was done focused on the BiciMAD station 252 which was right outside the Chamartín railway station. The hourly average number of trips to and from station 252 was compared with the five nearby BiciMAD stations (208, 209, 217, 248, 249) to find any underlying travel patterns. Also, the hourly averages of district-wise and barrio-wise journeys to and from station 252 were calculated. This was done for both weekday and weekend trips and visualised in the QGIS tool as well as using a colour scale graph in MS Excel.

The two BiciMAD stations having the highest number of connections with station 252 were chosen and the hourly travel patterns between these stations and station 252 were analysed. This was done to check the pattern of travel closer to an individual level. These selected stations were station 245 and stations 208 and 209. The BiciMAD trips beginning or ending in stations 208 and 209, situated in Plaza Castilla, were added up together and considered as one since these stations were located only 50 m apart.

The trips between stations 252 and 245 were examined to see if there were any intermodal trip chains involving BiciMAD station 252. The "user day code" of the journeys was used to identify the trips made between these two stations by the same user within a day. This code is the same for the same user on all journeys made within a day. To determine whether these journeys were made for the commute to and from work, the timings of the first-mile trips from station 245 to station 252 and the last-mile travels from station 252 to 245 were compared.

Finally, a comparison of the hourly averages in stations 208 and 209 before and after the implementation of station 252 in December 2020 was done. This was to understand if the installation of the new station 252 affected the hourly averages in stations 208 and 209. This comparison was made between November 2020 and March 2021. These months were selected for the comparison study because station 252 only had ridership data available for the six months from December 2020 to June 2021 and because it was important to pick months close to the installation date of station 252 to minimize the impact of other factors affecting ridership, such as weather.

4 Results

The results of the data analysis described in section 4.4 are presented in this section. The results are presented in different sub-sections for weekdays, weekends, and station-level analysis of BiciMAD station 252.

4.1 First-mile and Last-mile trips on weekdays

To start with, *Table 6* shows the average number of trips per hour ending in the twelve BiciMAD stations (first-mile trips) near Chamartín station during a weekday. In the table, the darker the shade of red, the higher the number of trips and vice versa. Also, we can see that the highest number of trips are concentrated during the peak hours in the morning and evening in almost all the BiciMAD stations.

Table 6: Hourly averages of first-mile trips on weekdays

	156	157	158	207	208	209	217	248	249	252	253	254
00:00:00	0.50	0.81	0.26	0.32	0.42	0.15	0.18	0.01	0.10	0.02	0.14	0.09
01:00:00	0.27	0.40	0.12	0.27	0.21	0.12	0.07	0.02	0.02	0.01	0.02	0.06
02:00:00	0.18	0.26	0.09	0.23	0.12	0.11	0.08	0.01	0.02	0.00	0.02	0.04
03:00:00	0.15	0.15	0.06	0.10	0.26	0.27	0.15	0.00	0.03	0.02	0.03	0.02
04:00:00	0.10	0.23	0.15	0.15	0.59	0.23	0.56	0.03	0.02	0.20	0.28	0.19
05:00:00	0.71	1.25	1.04	0.62	2.49	0.58	2.18	0.10	0.16	6.85	0.40	1.00
06:00:00	1.58	3.99	2.66	1.24	5.07	1.14	3.09	0.19	1.01	5.28	0.85	1.83
07:00:00	2.14	6.09	3.42	1.95	6.27	1.43	2.31	0.46	2.17	2.63	0.80	2.74
08:00:00	2.09	6.88	2.83	1.49	4.41	0.82	1.27	0.31	0.98	1.52	1.06	2.47
09:00:00	2.06	4.75	1.74	1.58	3.23	0.73	1.19	0.24	0.44	1.40	1.09	2.28
10:00:00	1.61	2.85	1.21	1.94	3.57	0.91	1.28	0.31	0.31	1.09	1.25	2.45
11:00:00	1.84	2.79	1.27	2.14	4.64	1.01	1.37	0.31	0.77	1.46	2.41	3.31
12:00:00	2.79	4.72	1.80	3.42	6.47	1.60	1.81	0.74	0.87	1.80	3.63	6.24
13:00:00	3.07	6.30	2.31	3.90	7.45	2.56	1.71	0.87	1.01	1.21	4.58	6.07
14:00:00	3.22	6.30	2.13	3.09	5.87	2.37	1.49	0.96	0.71	0.79	3.56	3.96
15:00:00	3.10	5.46	2.11	3.34	6.31	1.77	1.90	0.77	0.74	1.10	3.02	3.75
16:00:00	4.01	5.74	2.15	4.57	8.62	2.56	2.52	1.05	0.98	1.02	3.40	5.29
17:00:00	4.92	6.37	2.09	4.86	10.57	3.27	2.48	1.30	1.38	0.92	3.95	6.58
18:00:00	5.07	7.24	2.08	4.51	9.43	2.80	2.06	0.95	0.98	0.66	3.97	5.69
19:00:00	3.78	6.07	1.95	3.39	6.70	2.08	1.54	0.84	1.28	0.65	3.68	4.82
20:00:00	2.94	4.82	1.52	2.92	4.49	1.42	1.28	0.46	1.09	0.35	3.77	2.94
21:00:00	2.16	3.49	1.20	2.30	3.40	0.80	0.78	0.44	0.77	0.15	2.22	2.80
22:00:00	1.43	2.59	0.92	1.81	2.57	0.87	0.60	0.28	0.44	0.18	1.08	1.31
23:00:00	0.87	1.64	0.60	0.97	1.26	0.53	0.43	0.02	0.12	0.05	0.39	0.50

The average number of last-mile trips per hour which are originating from the twelve BiciMAD stations near the Chamartín railway station during the weekdays is shown in *Table 7* below. In the table, the darker the shade of green, the higher the number of trips and vice versa. As seen in the case of first-mile trips during the weekdays, it can be seen that the highest number of trips are concentrated during the peak hours in the morning and evening in almost all the BiciMAD stations.

Table 7: Hourly averages of last-mile trips on weekdays

	156	157	158	207	208	209	217	248	249	252	253	254
00:00:00	0.38	0.74	0.32	0.87	2.73	0.74	1.01	0.13	0.75	0.10	0.67	0.74
01:00:00	0.16	0.43	0.18	0.45	1.17	0.25	0.52	0.12	0.06	0.06	0.21	0.28
02:00:00	0.08	0.26	0.15	0.21	0.46	0.13	0.25	0.03	0.06	0.02	0.04	0.09
03:00:00	0.05	0.19	0.12	0.17	0.20	0.07	0.10	0.01	0.00	0.02	0.04	0.03
04:00:00	0.24	0.40	0.07	0.11	0.14	0.11	0.08	0.01	0.00	0.02	0.01	0.02
05:00:00	1.22	1.83	0.24	0.45	0.17	0.07	0.08	0.01	0.30	0.03	0.23	0.16
06:00:00	2.47	3.86	1.27	0.73	0.63	0.47	0.22	0.05	0.78	0.06	1.60	1.23
07:00:00	3.03	6.18	2.20	2.87	3.98	1.17	0.97	1.02	0.70	0.24	2.92	2.36
08:00:00	3.29	6.97	2.18	5.11	9.59	2.88	2.48	0.79	3.18	1.07	4.42	4.54
09:00:00	2.92	4.77	1.80	3.43	6.83	2.51	2.80	0.65	2.38	1.60	1.91	3.45
10:00:00	2.23	3.39	1.47	1.71	3.33	0.99	1.90	0.54	1.26	2.01	0.91	2.32
11:00:00	2.39	3.44	1.66	1.50	3.41	0.99	2.20	0.49	1.08	1.62	1.11	1.91
12:00:00	3.42	4.38	3.33	1.58	3.52	0.99	2.56	0.43	0.86	1.83	1.13	2.33
13:00:00	3.31	6.19	4.07	1.58	5.24	1.30	2.97	0.46	1.05	2.68	1.61	2.69
14:00:00	3.19	5.77	3.69	2.38	6.05	2.03	5.04	0.67	2.22	5.60	2.52	4.25
15:00:00	3.17	5.72	2.71	3.26	5.37	1.86	4.90	0.46	1.26	5.36	2.52	5.51
16:00:00	3.49	5.84	2.82	2.43	4.93	1.41	3.81	0.34	1.11	1.14	2.56	3.80
17:00:00	3.98	6.43	3.12	3.10	5.72	1.73	4.79	0.69	2.34	1.13	2.65	4.24
18:00:00	4.80	6.85	3.08	3.77	7.56	2.39	6.31	0.89	3.89	1.16	4.05	5.50
19:00:00	4.20	5.56	2.79	4.16	8.36	2.62	5.95	1.01	3.64	1.30	4.31	5.56
20:00:00	3.57	4.41	1.72	3.44	7.46	2.52	4.42	1.19	1.86	1.02	2.94	5.43
21:00:00	2.64	3.10	1.22	2.45	5.97	2.13	2.78	0.82	1.16	0.86	2.31	3.13
22:00:00	1.75	2.23	0.89	2.00	4.84	2.03	2.33	0.46	1.27	0.97	1.60	3.13
23:00:00	0.93	1.25	0.63	1.79	4.22	1.68	1.80	0.17	0.27	0.17	1.39	2.31

Figure 16 below shows a graphic representation of the hourly averages of first-mile trips during the weekdays that ended at each of the 12 BiciMAD stations close to the Chamartín train station region. The graph highlights BiciMAD station 252, which is situated outside the Chamartín railway station. It can be seen in the graph that Station 252 has a high demand just in the morning for first-mile rides, as opposed to other BiciMAD stations that have visible peak demand during the morning and the evening.

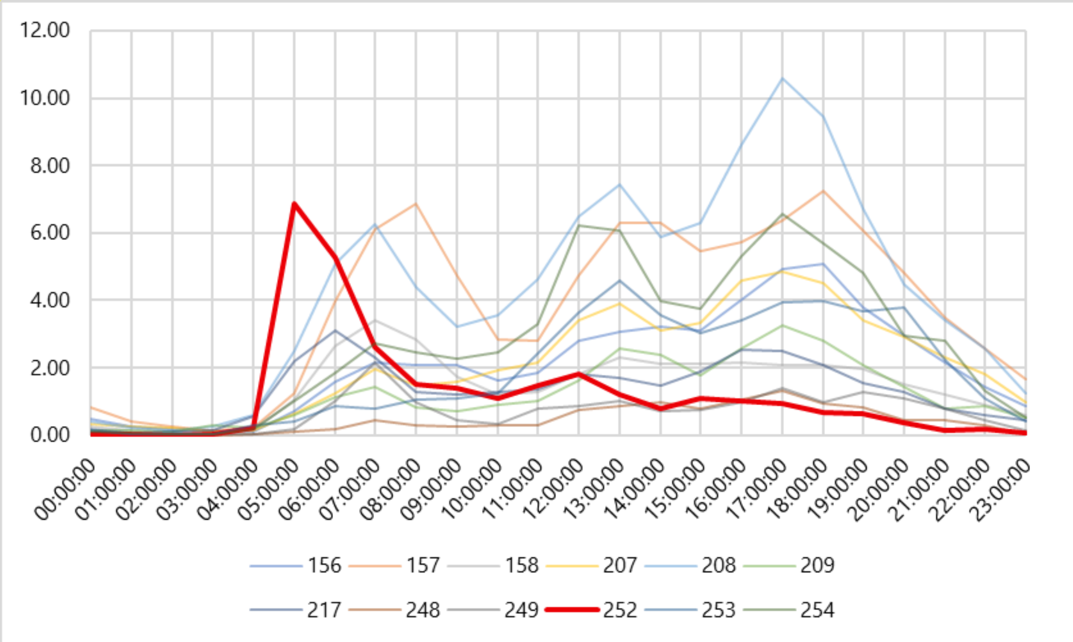

Figure 16: Hourly average number of first-mile trips on weekdays

The average number of last-mile trips per hour originating from the twelve BiciMAD stations during the weekdays near the Chamartín station area is shown graphically in figure 17. Similar to the first-mile trips during weekdays, unlike other BiciMAD stations, station 252 has only one visible peak which is in the evening in the case of last-mile trips.

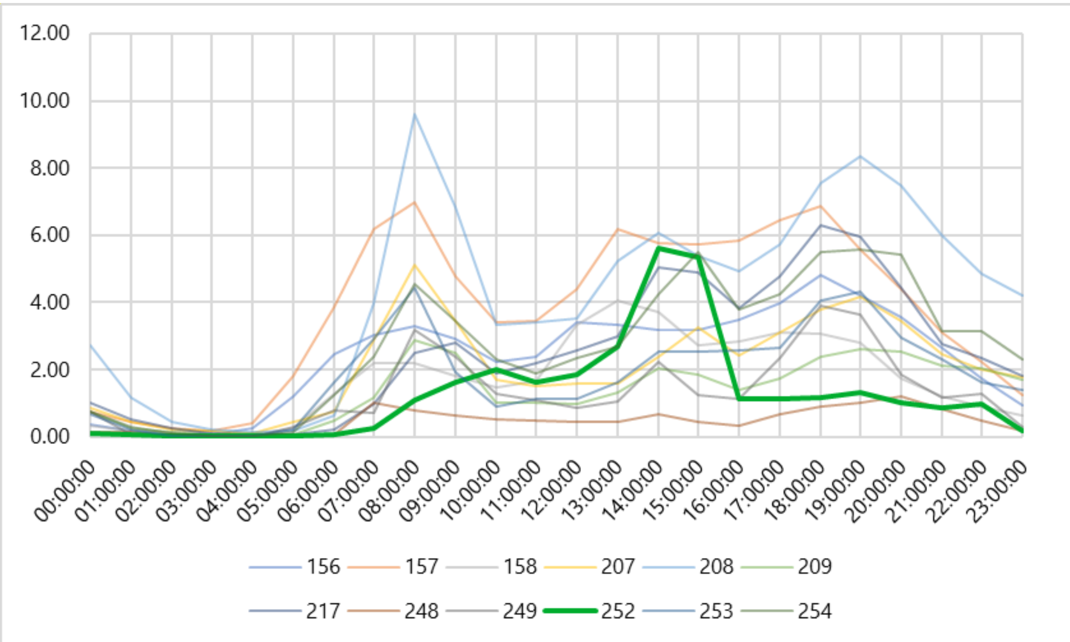

Figure 17: Hourly average number of last-mile trips on weekdays

The results of the analysis on the origin of the first-mile trips, during the weekdays, ending in the twelve BiciMAD stations are presented in *Figure 18* and *Figure 19* below. The larger the radius of the circle, the higher the number of trips originating from that district or barrio. The origin districts of these first-mile trips during weekdays are shown in *Figure 18*.

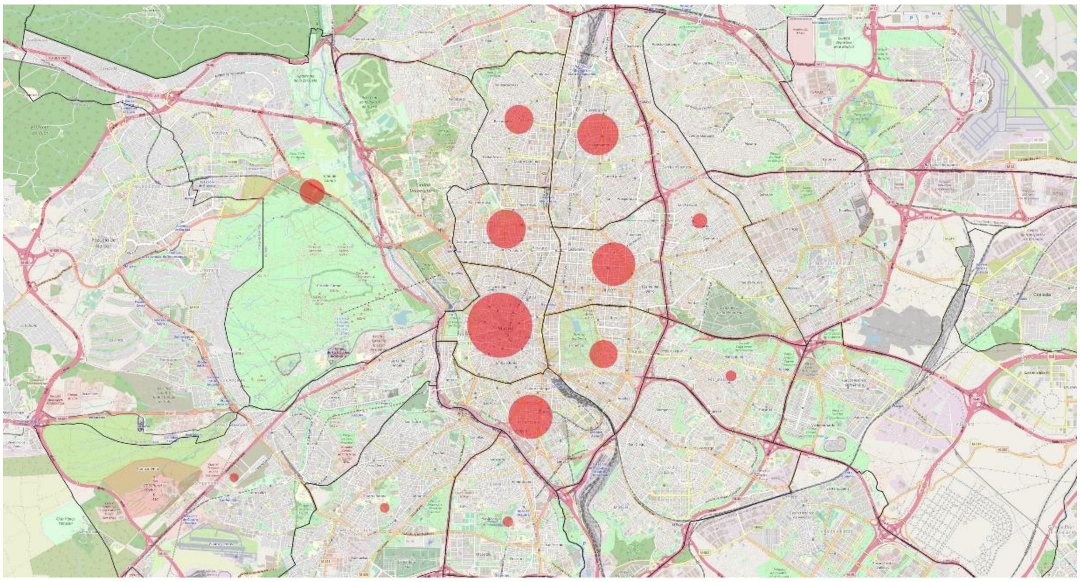

Figure 18: Origin districts of first-mile trips on weekdays to the Chamartín area

Figure 19 shows the barrios from which the first-mile trips on weekdays originate. From these figures, it can be seen that most of the trips are originating from the city centre, from the district of Centro.

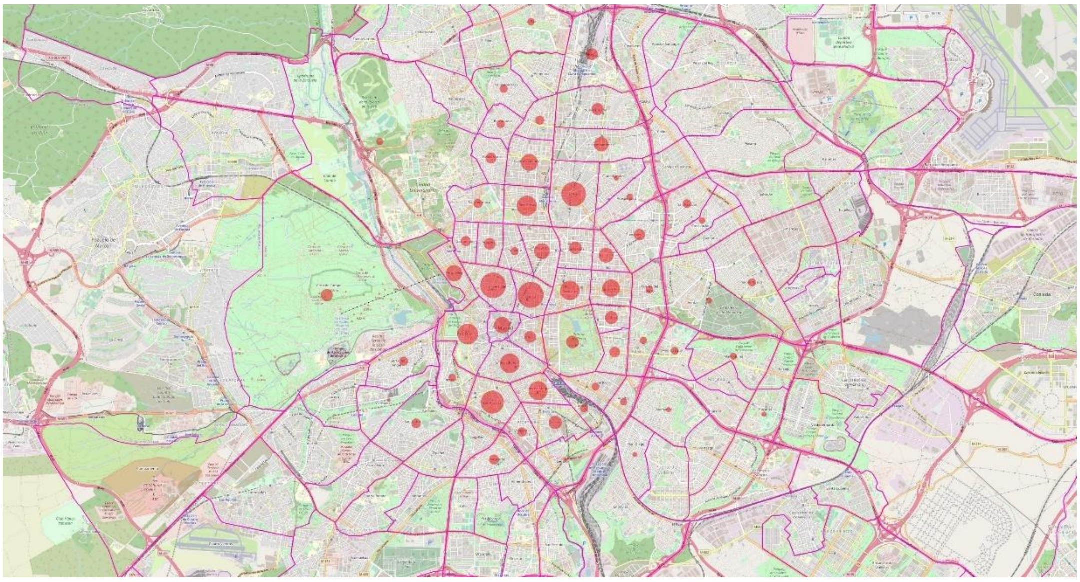

Figure 19: Origin barrios of first-mile trips on weekdays to the Chamartín area

The destination of the last-mile trips, during the weekdays, beginning from the twelve BiciMAD stations near Chamartín railway station are presented in *Figure 20* and *Figure 21* below. The districts in which the last-mile trips during weekdays originating from the Chamartín railway station area end are shown in *Figure 20*.

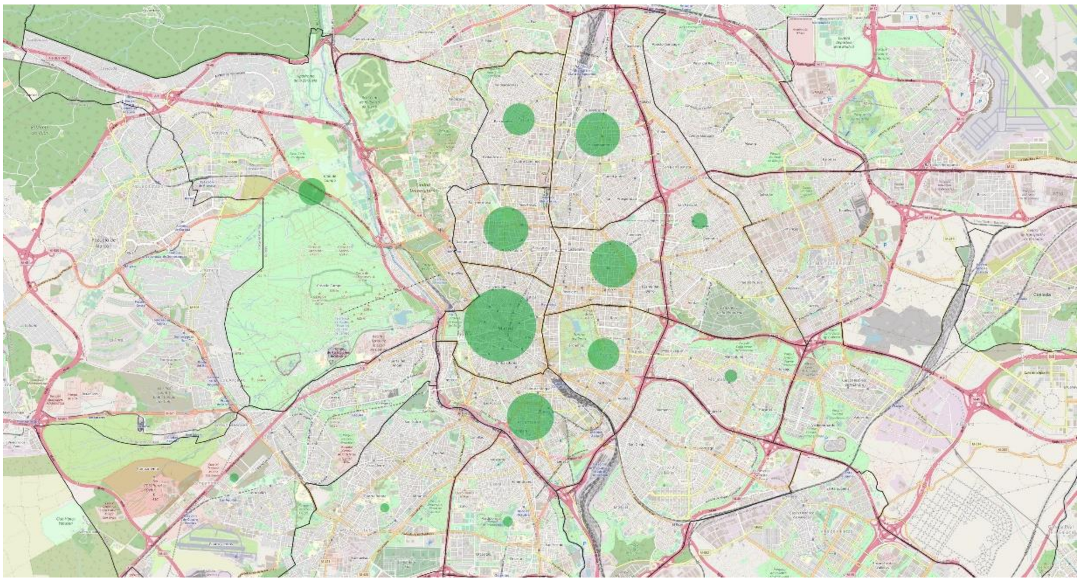

Figure 20: Destination districts of last-mile trips on weekdays from the Chamartín area

Figure 21 shows the destination barrios of the last-mile trips during weekdays. Like first-mile journeys made during the weekdays, the majority of these trips conclude in the Centro district.

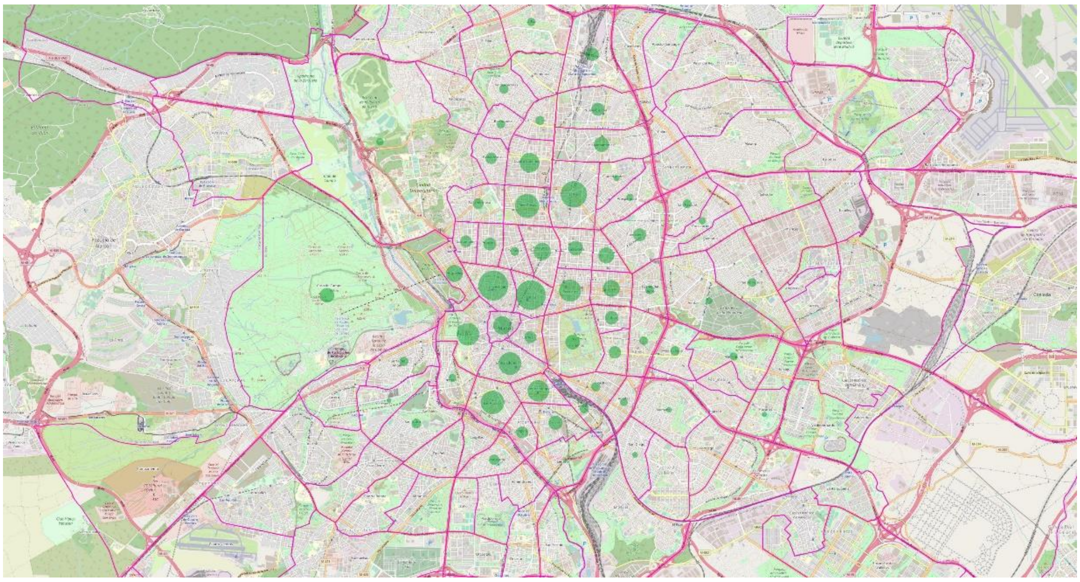

Figure 21: Destination barrios of last-mile trips on weekdays from the Chamartín area

4.2 First-mile and Last-mile trips on weekends

Table 8 below shows the hourly average number of first-mile trips ending in the twelve BiciMAD stations near Chamartín station during the weekends. More trips are represented in the table by darker red tones, whereas fewer journeys are represented by lighter shades of red. Unlike in the case of weekdays, we cannot see any patterns in the table, that show that the trips are concentrated to a certain period in the day in any of the twelve BiciMAD stations.

Table 8: Hourly averages of first-mile trips on weekends

	156	157	158	207	208	209	217	248	249	252	253	254
00:00:00	1.05	1.97	0.54	1.23	1.14	0.48	0.43	0.06	0.10	0.06	0.42	0.51
01:00:00	0.71	1.41	0.41	0.90	1.15	0.36	0.29	0.18	0.04	0.02	0.24	0.25
02:00:00	0.60	1.12	0.38	0.92	0.69	0.25	0.27	0.02	0.12	0.00	0.22	0.24
03:00:00	0.53	0.77	0.28	0.61	0.59	0.36	0.14	0.08	0.02	0.02	0.20	0.06
04:00:00	0.52	0.47	0.19	0.39	0.50	0.07	0.19	0.04	0.00	0.08	0.22	0.16
05:00:00	0.41	0.51	0.13	0.34	0.38	0.08	0.53	0.04	0.02	1.12	0.10	0.20
06:00:00	0.56	0.43	0.12	0.39	0.66	0.16	0.93	0.06	0.10	1.27	0.38	0.59
07:00:00	1.31	1.00	0.36	0.56	1.25	0.38	1.06	0.50	0.28	1.08	0.54	1.06
08:00:00	1.30	1.34	0.41	1.16	2.32	0.67	1.07	0.32	0.22	0.71	0.90	0.92
09:00:00	1.98	1.93	0.50	1.62	2.77	0.67	1.69	0.46	0.32	0.59	1.00	1.25
10:00:00	2.19	2.26	0.58	1.48	4.06	0.93	1.66	0.34	0.44	0.47	1.46	2.22
11:00:00	2.93	2.97	0.88	2.01	5.03	0.91	2.00	0.50	0.48	0.80	2.20	4.08
12:00:00	2.77	3.26	1.08	2.22	5.81	1.13	1.75	0.64	0.82	1.25	3.32	4.69
13:00:00	2.52	3.23	0.91	2.18	4.66	1.14	1.47	0.48	0.52	0.49	2.60	3.61
14:00:00	2.85	2.84	0.78	1.55	3.96	1.08	1.06	0.50	0.50	0.35	1.66	2.02
15:00:00	2.30	3.12	0.76	1.92	4.36	1.38	1.63	0.34	0.64	0.49	1.84	2.41
16:00:00	2.62	3.17	0.93	2.24	5.39	1.71	1.67	0.66	0.52	0.57	2.08	3.45
17:00:00	2.65	3.49	1.13	2.31	5.88	2.07	1.69	0.62	0.60	0.61	2.06	3.55
18:00:00	2.45	3.71	1.39	2.82	5.74	1.76	1.38	0.66	0.74	0.65	2.68	3.55
19:00:00	1.74	3.57	1.18	2.58	4.91	1.16	1.36	0.46	0.86	0.49	2.78	2.73
20:00:00	1.29	3.06	1.08	2.13	3.70	0.74	1.17	0.62	0.76	0.41	2.98	2.73
21:00:00	1.51	2.64	0.92	1.85	3.13	0.59	0.83	0.46	0.94	0.20	2.46	2.31
22:00:00	1.02	2.61	0.67	1.66	2.53	0.80	0.62	0.46	0.52	0.06	1.48	1.39
23:00:00	0.72	1.40	0.48	1.07	1.28	0.44	0.47	0.14	0.24	0.02	0.56	0.53

Table 9 below displays the average number of last-mile journeys per hour that start at the twelve BiciMAD stations nearby the Chamartín railway station on the weekends. The darker colours of green in the table indicate more trips, while the lighter hues indicate fewer trips during that hour. As was in the case of first-mile trips during the weekends, no discernible patterns could

be found in any of the twelve BiciMAD stations that the last-mile trips originate from during the weekends.

Table 9: Hourly averages of last-mile trips on Weekends

	156	157	158	207	208	209	217	248	249	252	253	254
00:00:00	0.71	1.49	0.67	1.61	3.33	0.99	1.58	0.10	0.68	0.20	0.64	1.40
01:00:00	0.60	1.12	0.59	1.01	2.84	0.74	1.21	0.14	0.20	0.14	0.80	1.14
02:00:00	0.48	1.03	0.40	0.91	1.55	0.44	0.71	0.16	0.16	0.10	0.30	0.36
03:00:00	0.48	0.64	0.26	0.62	0.92	0.32	0.46	0.08	0.16	0.14	0.22	0.42
04:00:00	0.33	0.64	0.20	0.57	0.74	0.24	0.36	0.00	0.04	0.02	0.12	0.24
05:00:00	0.31	0.60	0.14	0.67	0.45	0.15	0.32	0.02	0.04	0.10	0.26	0.12
06:00:00	0.29	0.73	0.19	0.31	0.54	0.17	0.20	0.04	0.40	0.06	0.22	0.14
07:00:00	0.50	0.92	0.17	0.25	0.41	0.17	0.21	0.06	0.30	0.30	0.52	0.28
08:00:00	1.12	1.36	0.46	0.44	0.76	0.27	0.48	0.22	0.34	0.72	0.68	1.00
09:00:00	1.48	1.92	0.70	1.01	1.72	0.70	0.97	0.27	0.80	0.46	1.38	2.00
10:00:00	2.36	2.96	0.93	1.71	2.76	0.86	1.50	0.29	0.96	0.92	1.82	2.16
11:00:00	3.09	3.43	1.00	2.06	3.76	0.96	2.55	0.82	1.32	0.58	2.78	2.26
12:00:00	3.10	3.51	1.23	2.52	4.37	1.21	3.33	0.69	1.24	0.56	2.40	2.84
13:00:00	2.85	3.15	1.06	2.58	5.20	1.83	3.97	0.98	1.40	0.86	3.24	3.66
14:00:00	2.60	3.00	1.04	2.60	5.14	1.49	3.37	0.53	1.44	1.02	2.46	3.76
15:00:00	2.94	2.78	1.09	1.74	3.55	1.01	2.86	0.45	0.82	1.06	1.98	2.78
16:00:00	3.07	3.33	1.09	1.74	3.72	0.93	2.58	0.31	0.94	0.44	2.12	2.50
17:00:00	3.19	3.56	1.26	2.34	4.11	1.07	3.38	0.57	1.94	0.38	2.76	3.40
18:00:00	3.15	3.58	1.33	2.50	4.49	1.52	3.81	0.76	1.24	0.42	2.52	3.30
19:00:00	2.44	3.18	1.20	1.90	4.76	1.45	4.31	0.71	1.24	0.72	2.24	3.10
20:00:00	1.99	2.92	1.25	1.98	5.27	1.95	3.93	0.69	0.70	0.52	2.00	2.88
21:00:00	1.48	2.21	0.90	1.80	4.71	1.64	2.60	0.45	1.02	0.58	1.56	2.52
22:00:00	0.99	1.75	0.80	1.58	4.05	1.49	1.96	0.39	0.64	1.14	1.64	2.36
23:00:00	0.52	1.15	0.59	1.53	3.74	1.04	1.88	0.29	0.20	0.38	1.20	2.12

The hourly averages of first-mile trips during the weekends that came to an end at each of the 12 BiciMAD stations nearby the Chamartín train station are represented graphically in *Figure 22* below. BiciMAD station 252, which is located outside the Chamartín train station, is highlighted in the graph. The data shows that Station 252 has a nearly constant demand throughout the day on weekends, in contrast to first-mile trips during the weekend which showed a peak in the morning. This is similar to the patterns observed in the other eleven BiciMAD stations during the weekends where no clear peak could be identified from the graph.

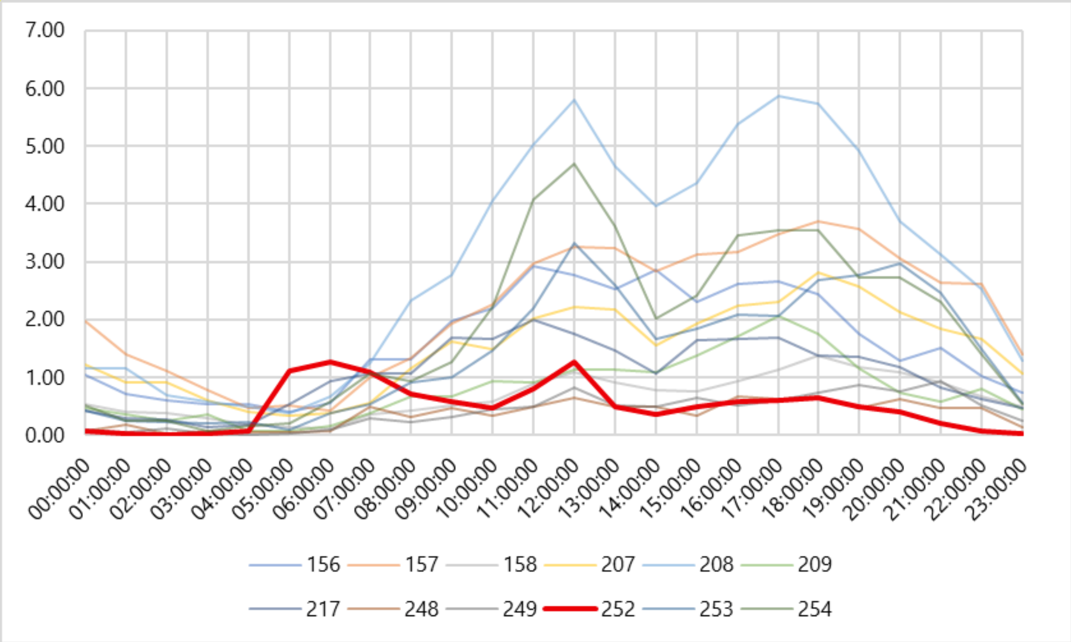

Figure 22: Hourly average number of first-mile trips on weekends

Figure 23 depicts visually the average number of last-mile journeys per hour during the weekends beginning from the twelve BiciMAD stations close to the Chamartín station region. Like other BiciMAD stations, station 252 does not have a noticeable peak that might be seen throughout the weekend, similar to the first-mile trips during weekends.

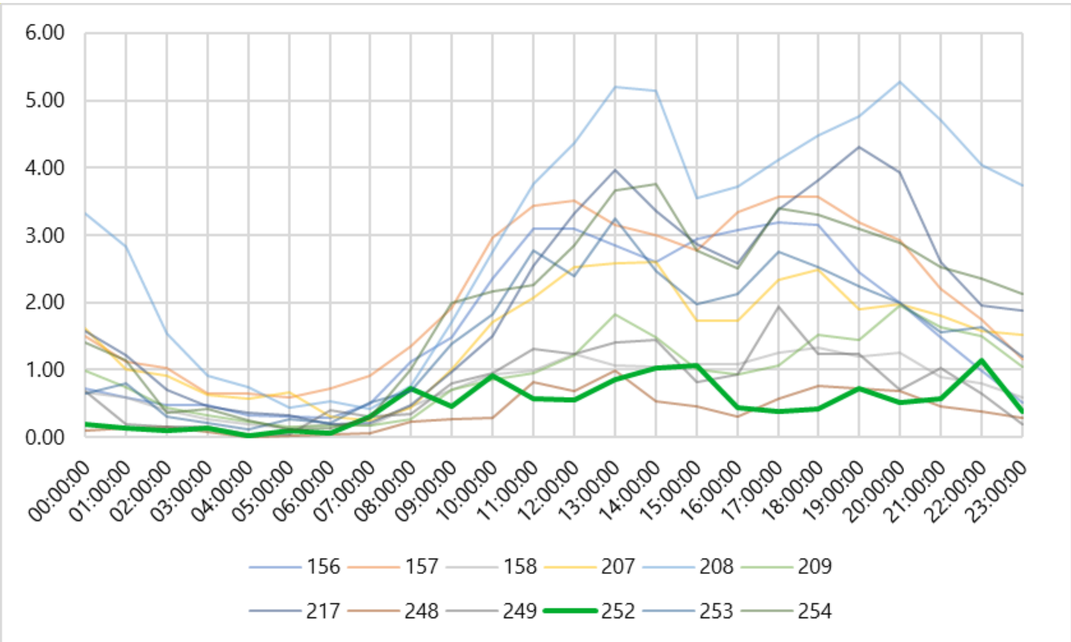

Figure 23: Hourly average number of last-mile trips on weekends

Figure 24 and *Figure 25* show the findings of the analysis on the first-mile trips during the weekends, ending at the twelve BiciMAD stations nearby Chamartín railway station. The larger the radius of the circle, the higher the number of trips beginning from that district or barrio. *Figure 24* displays the origin districts for these first-mile journeys made on the weekends.

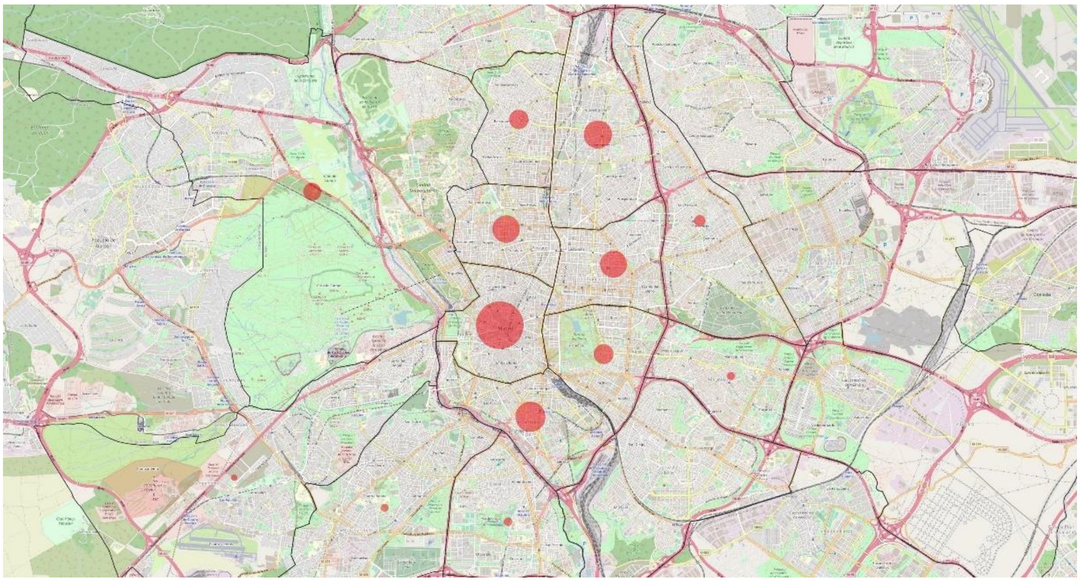

Figure 24: Origin districts of first-mile trips on weekends to the Chamartín area

The barrios from which first-mile journeys on weekends begin are shown in *Figure 25*. As in the case of first-mile trips during weekdays, a larger number of first-mile trips during weekends is also from the city centre.

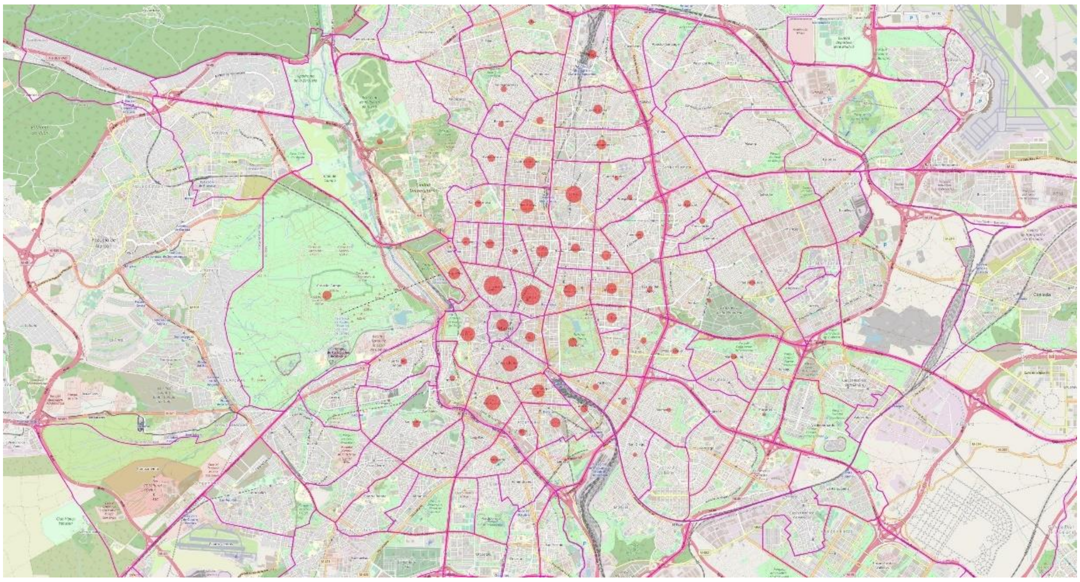

Figure 25: Origin barrios of first-mile trips on weekends to the Chamartín area

Figure 26 and *Figure 27* show the final destination of last-mile trips during weekends that start from the twelve BiciMAD stations close to Chamartín Railway Station. *Figure 26* below depicts the districts where weekend last-mile journeys coming from the Chamartín railway station area end.

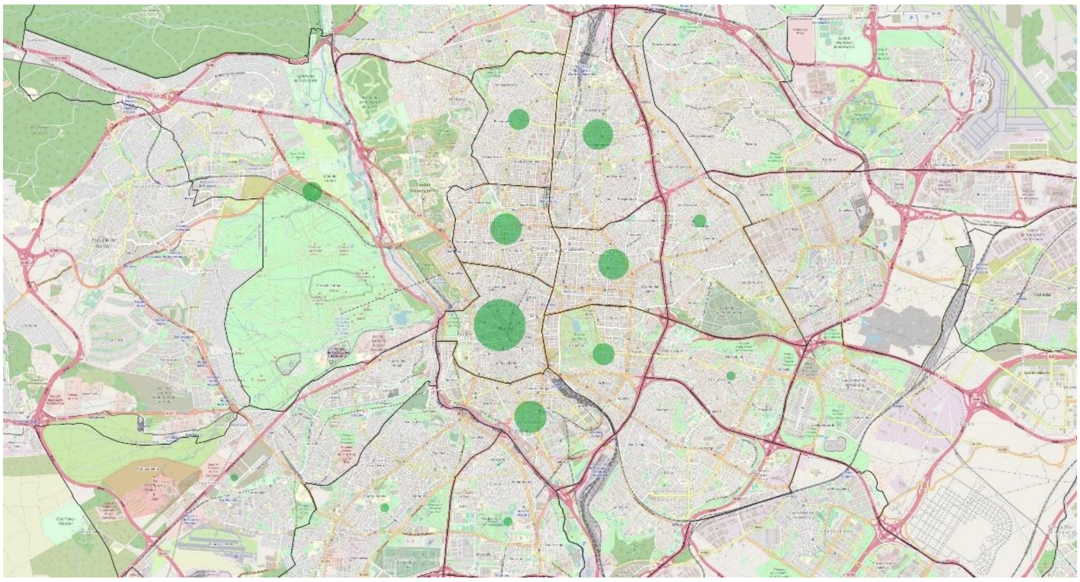

Figure 26: Destination districts of last-mile trips on weekends from the Chamartín area

The last-mile destinations for weekend trips are shown in *Figure 27*. Similar to the first-mile trips, most last-mile trips during weekends are concentrated in the city centre.

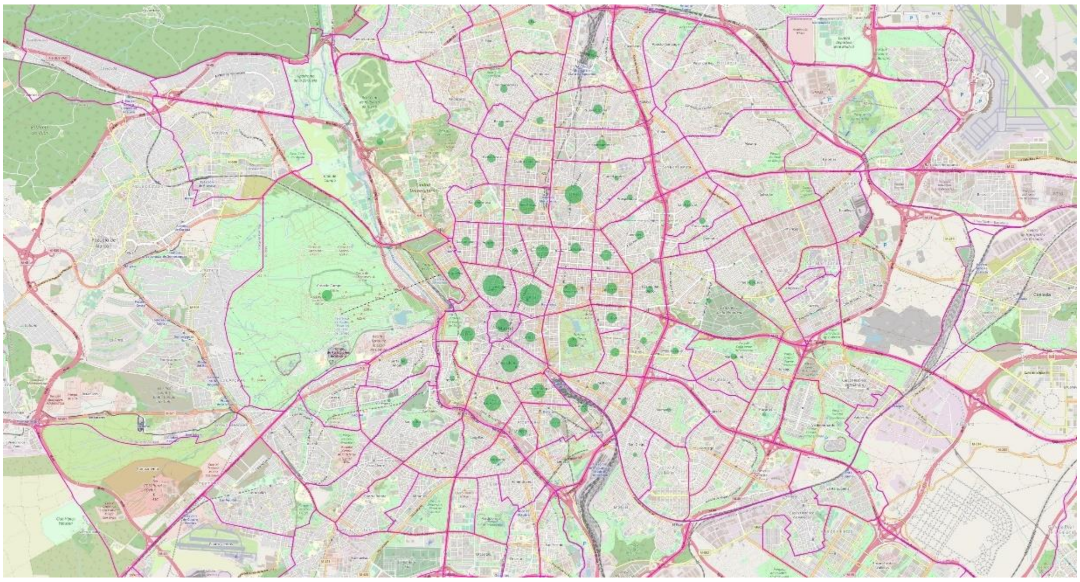

Figure 27: Destination barrios of last-mile trips on weekends from the Chamartín area

4.3 Station-level analysis – BiciMAD station 252

The average hourly ridership of the five closest BiciMAD stations (208, 209, 217, 248, 249) to station 252 is presented in *Figure 28*, *Figure 29*, *Figure 30*, and *Figure 31*. Stations 208 and 209 are combined as mentioned previously.

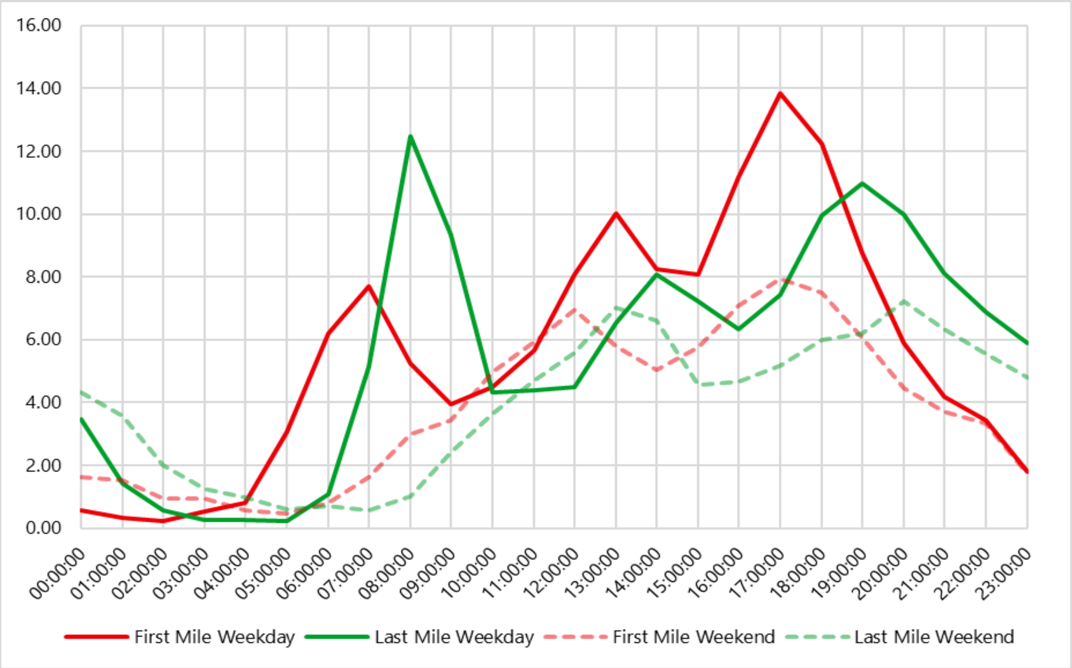

Figure 28: Average hourly ridership in BiciMAD stations 208 & 209 combined

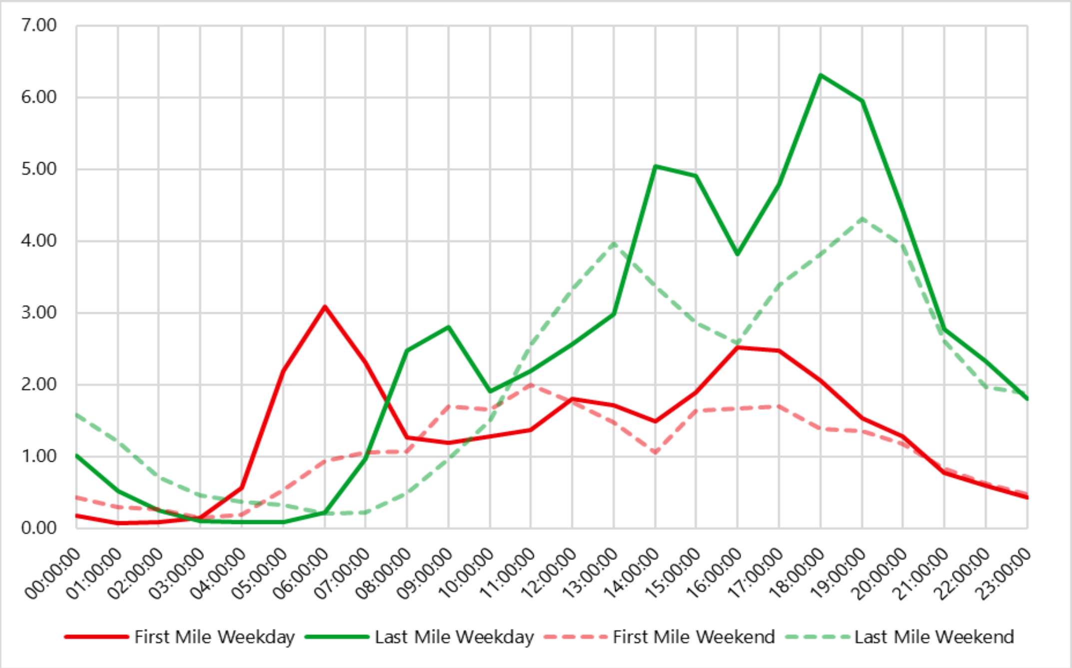

Figure 29: Average hourly ridership in BiciMAD station 217

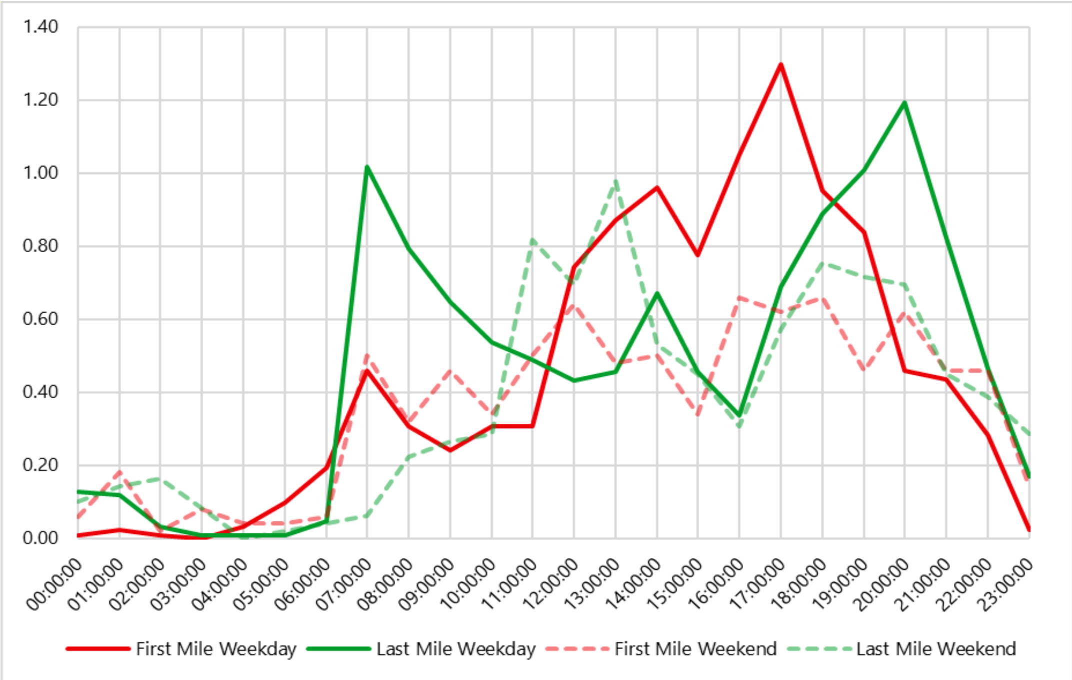

Figure 30: Average hourly ridership in BiciMAD station 248

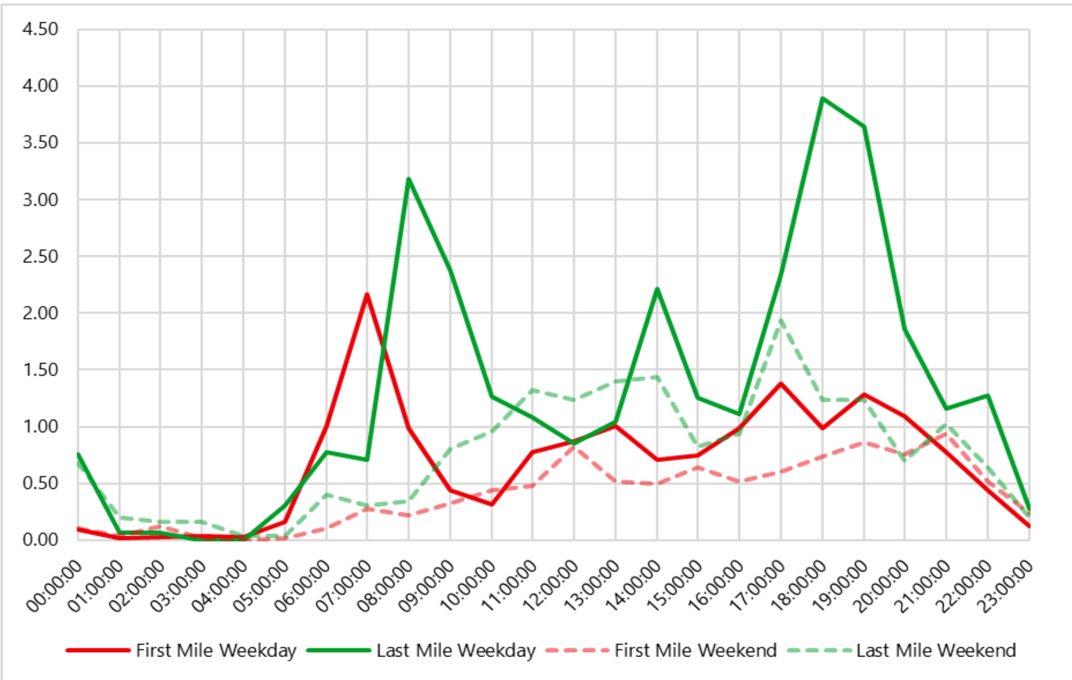

Figure 31: Average hourly ridership in BiciMAD station 249

The average hourly ridership at the BiciMAD station 252 for the first-mile and last-mile trips during the weekdays and weekends is shown in *Figure 32*. Unlike the nearby stations, station 252 shows a clear and distinct peak period for the first-mile and last-mile trips during the weekdays.

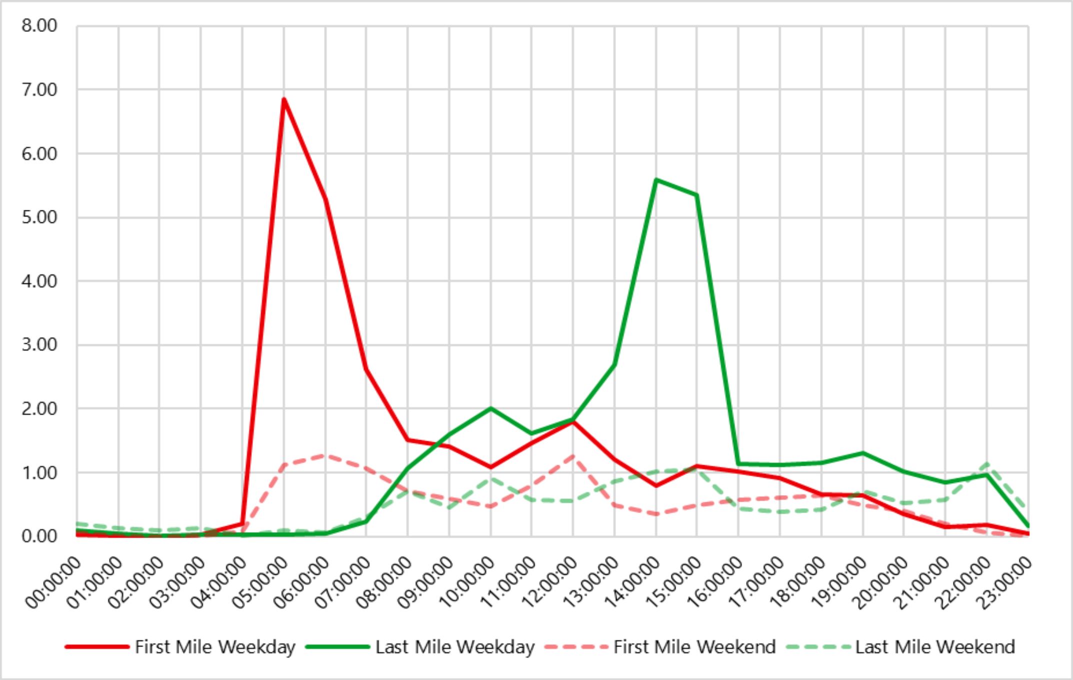

Figure 32: Average hourly ridership in BiciMAD station 252

4.3.1 Ridership analysis for weekdays at station 252

Figure 33 represents the results of the hourly average of weekday first-mile trips originating from different districts to BiciMAD station 252. It can be seen that the highest number of trips happen during the morning peak period from all of the districts.

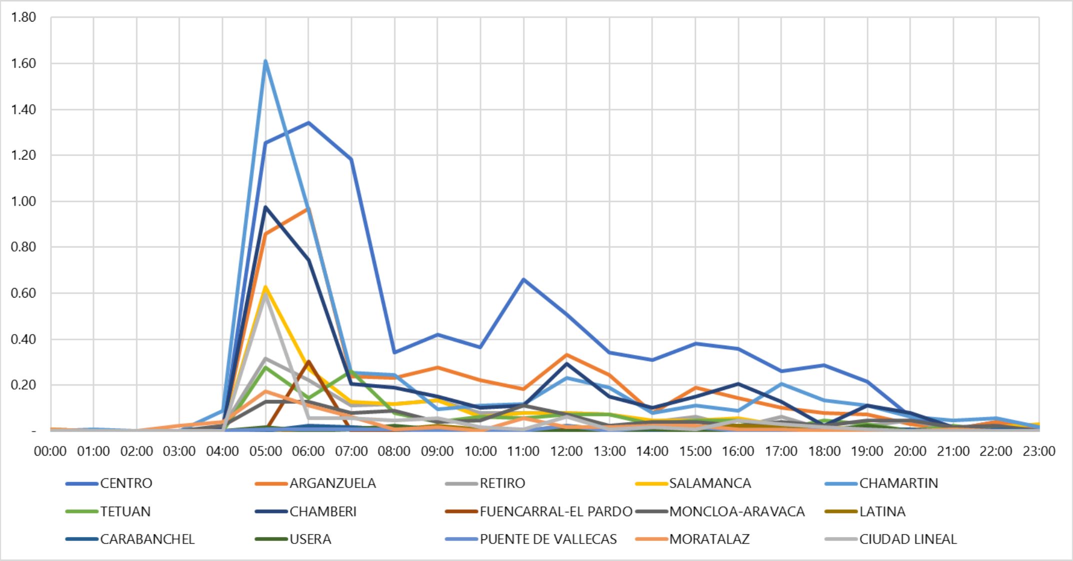

Figure 33: Average hourly ridership from origin districts during weekdays for first-mile trips ending at BiciMAD station 252

Figure 34 and *Figure 35* show the origin of the first-mile trips during weekdays that end in BiciMAD station 252 outside Chamartín railway station. The larger the radius of the circle, the higher the number of trips beginning from that district or barrio. *Figure 34* below shows the districts from which weekday first-mile journeys to BiciMAD station 252 begin.

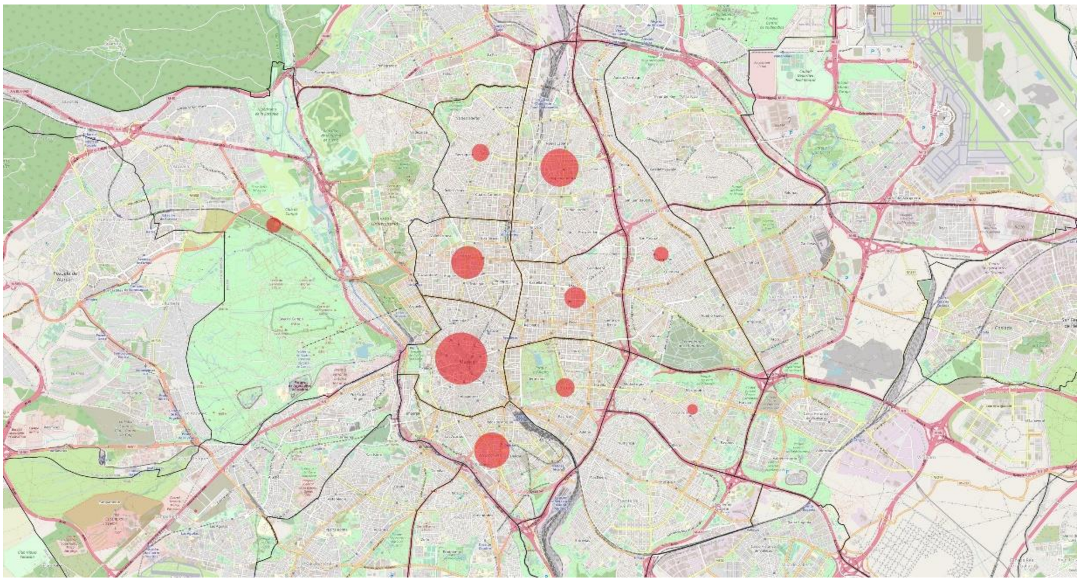

Figure 34: Origin districts of first-mile trips on weekdays to BiciMAD station 252

The barrios from which first-mile journeys on weekdays begin are shown in *Figure 35*. As in the case of the Chamartín station area analysis, a larger number of weekday first-mile trips to station 252 are also from the city centre.

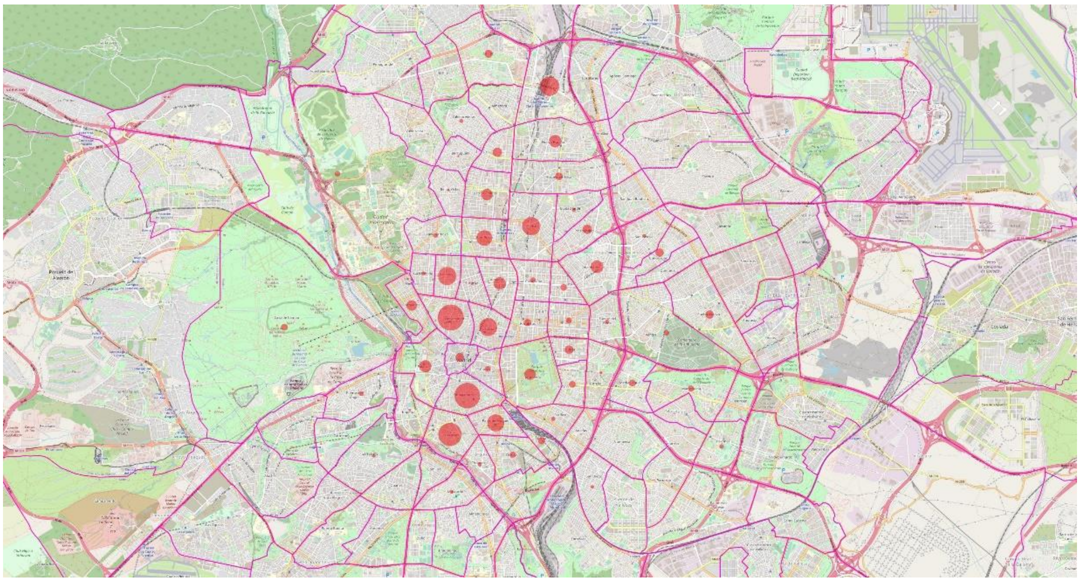

Figure 35: Origin barrios of first-mile trips on weekdays to BiciMAD station 252

The average number of last-mile trips from BiciMAD station 252 on weekdays that ended in various districts is depicted in *Figure 36*. It can be seen that most trips to all of the districts, happen during the evening peak period.

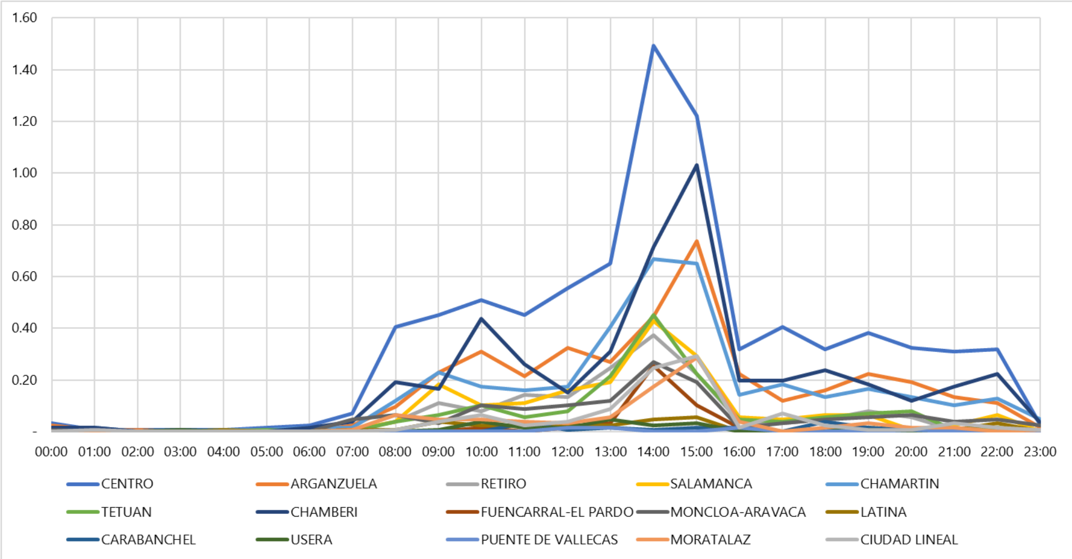

Figure 36: Average hourly ridership to destination districts during weekdays for last-mile trips starting at BiciMAD station 252

Figure 37 and *Figure 38* depict the final destination of last-mile journeys made during the weekdays from BiciMAD station 252 outside Chamartín Railway Station. *Figure 37* below shows the districts to which weekday last-mile journeys from BiciMAD station 252 end.

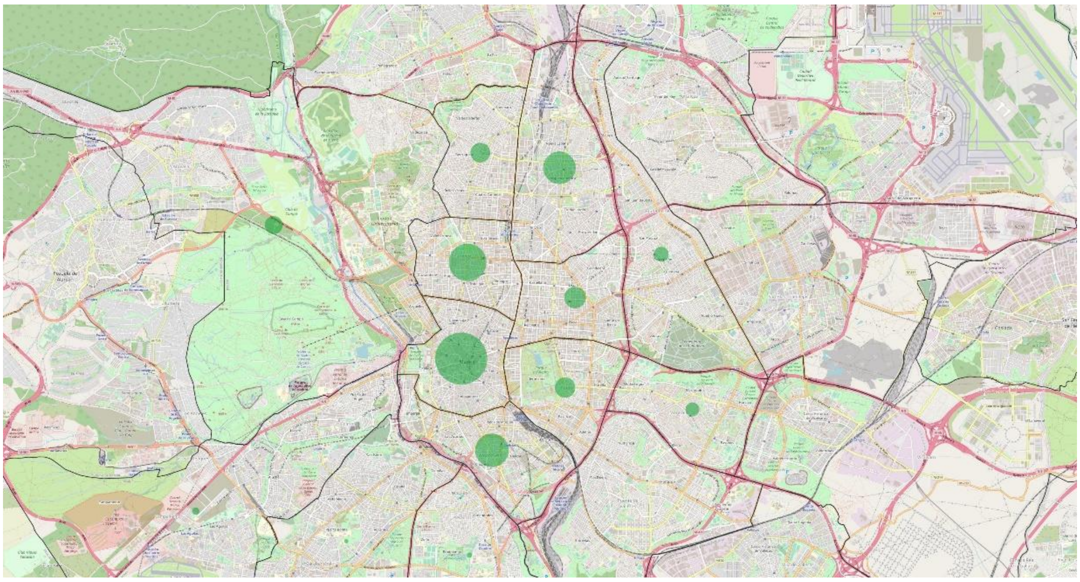

Figure 37: Destination districts of last-mile trips on weekdays from BiciMAD station 252

The barrios to which weekday last-mile journeys from station 252 end are shown in *Figure 38*. As in the case of the weekday first-mile trips to station 252, the majority of the last-mile trips are also towards the city centre.

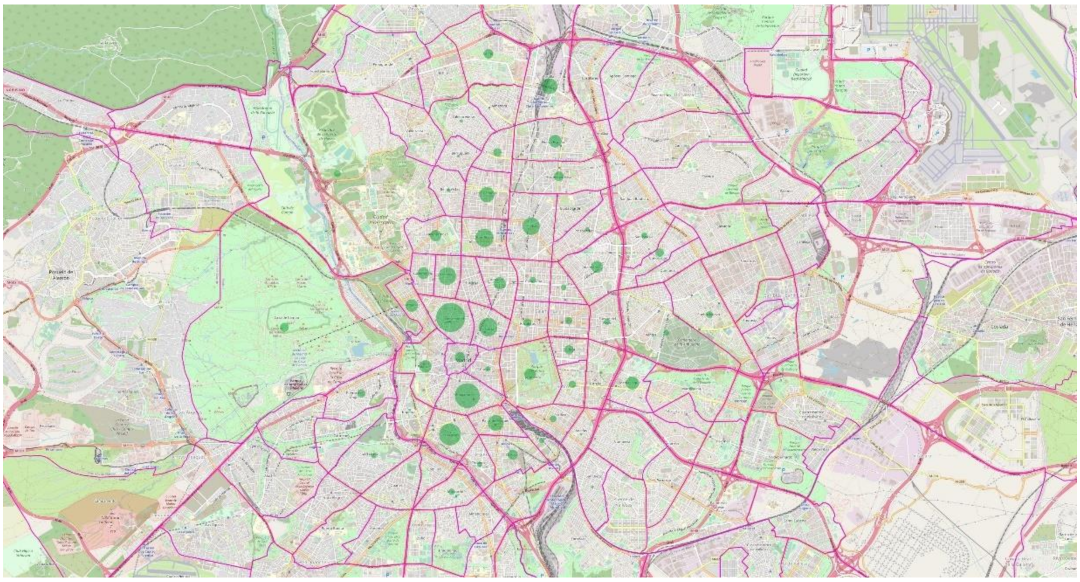

Figure 38: Destination barrios of last-mile trips on weekdays from BiciMAD station 252

4.3.2 Ridership analysis for weekends at station 252

Figure 39 represents the average number of first-mile trips during weekends originating from different districts to BiciMAD station 252. Unlike the first-mile trips on weekdays, there aren't any clear peaks for the weekend trips.

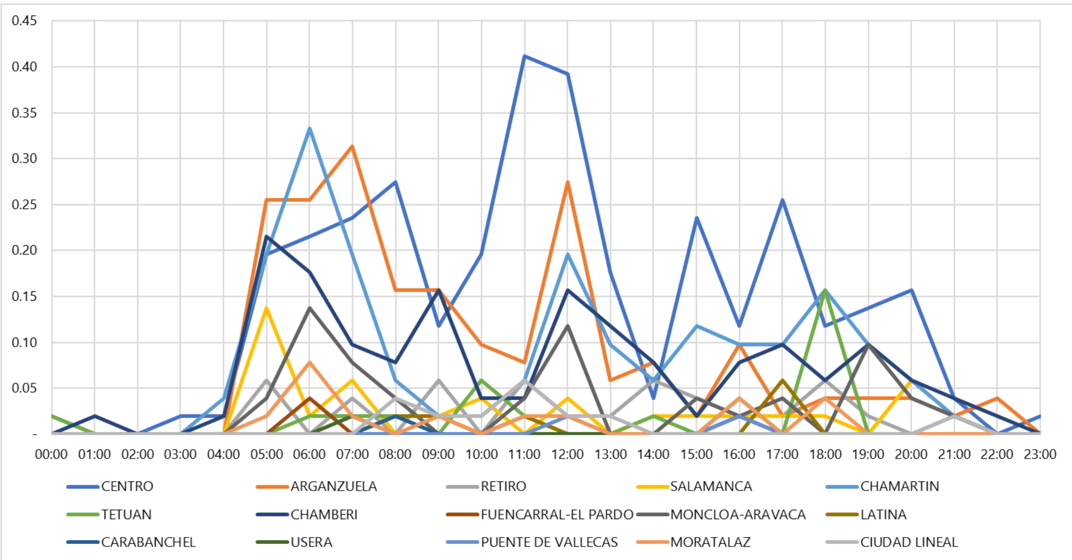

Figure 39: Average hourly ridership from origin districts during weekends for first-mile trips ending at BiciMAD station 252

Figure 40 and *Figure 41* show the results of the analysis on the origin of the first-mile trip during the weekends, ending at BiciMAD station 252. It can be seen that the number of trips is relatively low for each of the districts compared to the weekdays. *Figure 40* displays the origin districts for the first-mile journeys made during the weekend to BiciMAD station 252.

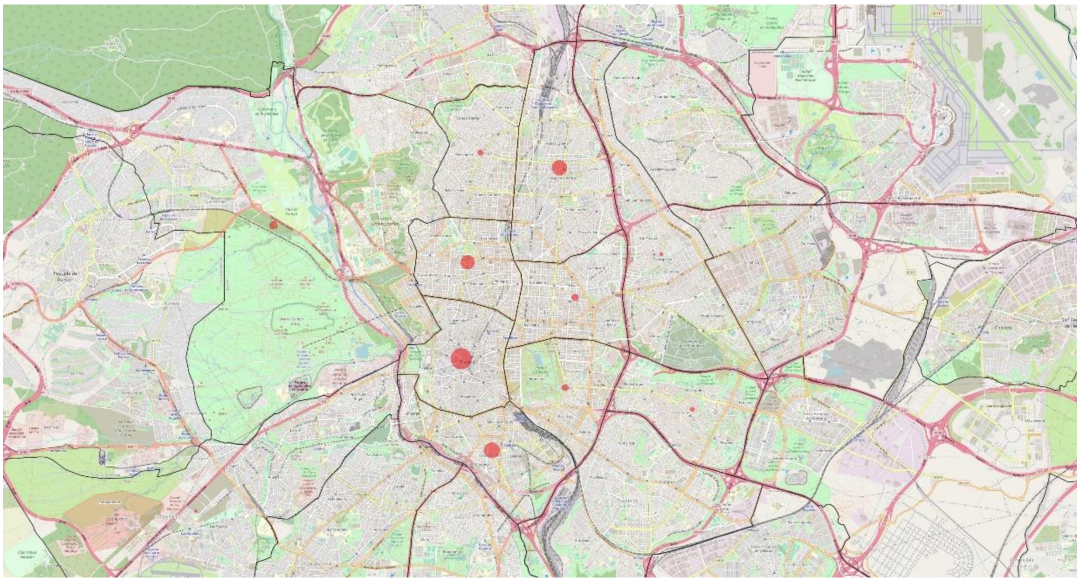

Figure 40: Origin districts of first-mile trips on weekends to BiciMAD station 252

The barrios from which the weekend first-mile journeys are made are shown in *Figure 41*. Again, a larger number of first-mile trips to station 252 originate from the heart of the city.

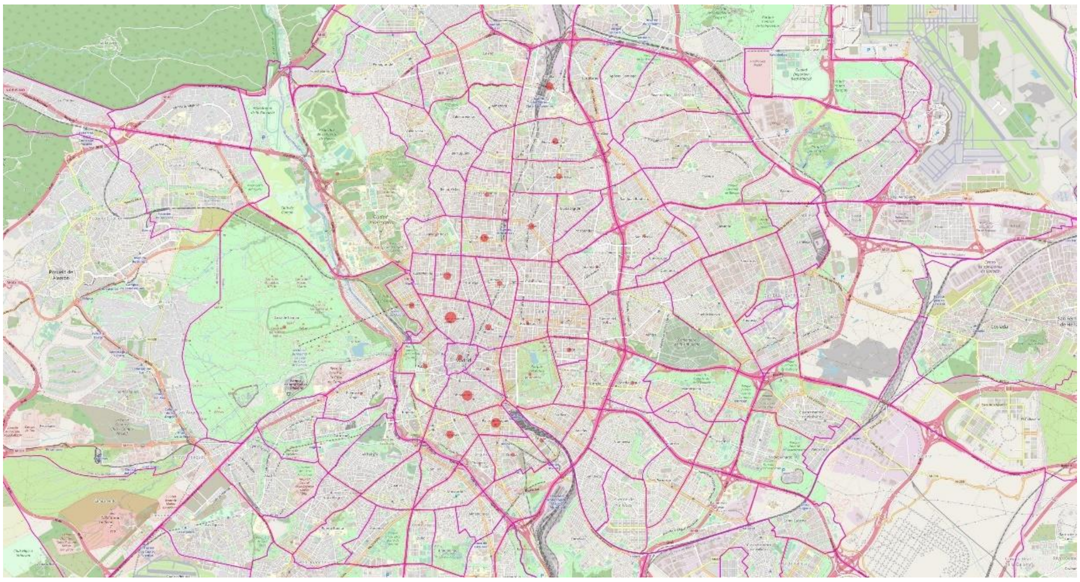

Figure 41: Origin barrios of first-mile trips on weekends to BiciMAD station 252

Figure 42 displays the hourly average of last-mile trips from BiciMAD station 252 on weekends that ended in various districts. There are no discernible patterns to be seen in any of the districts, much like with first-mile travels.

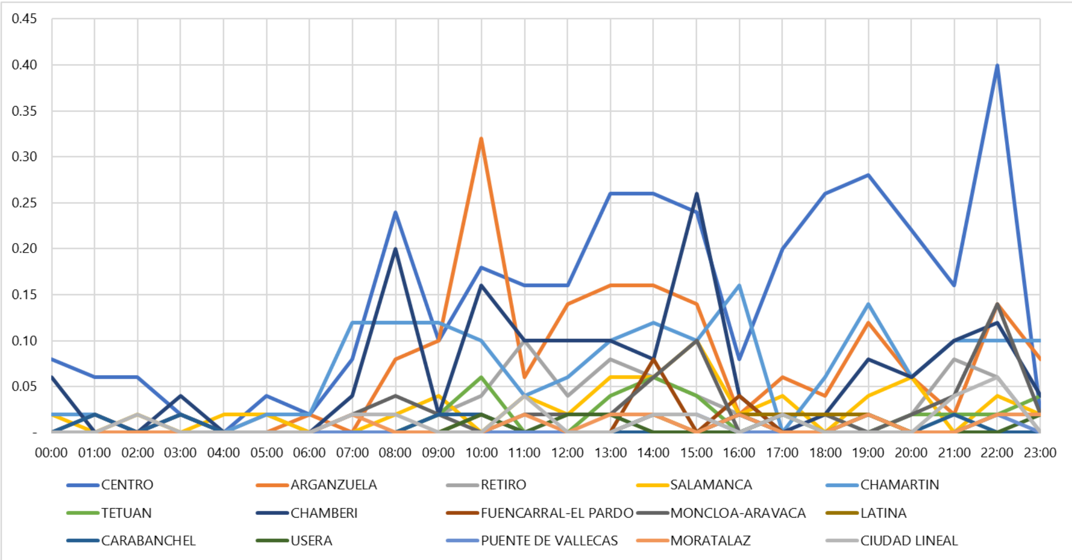

Figure 42: Average hourly ridership to destination districts during weekends for last-mile trips starting at BiciMAD station 252

The results of the analysis of the destination of trips originating from station 252 during weekends are shown in *Figure 43* and *Figure 44*. *Figure 43* below shows the districts to which weekend last-mile journeys from BiciMAD station 252 end.

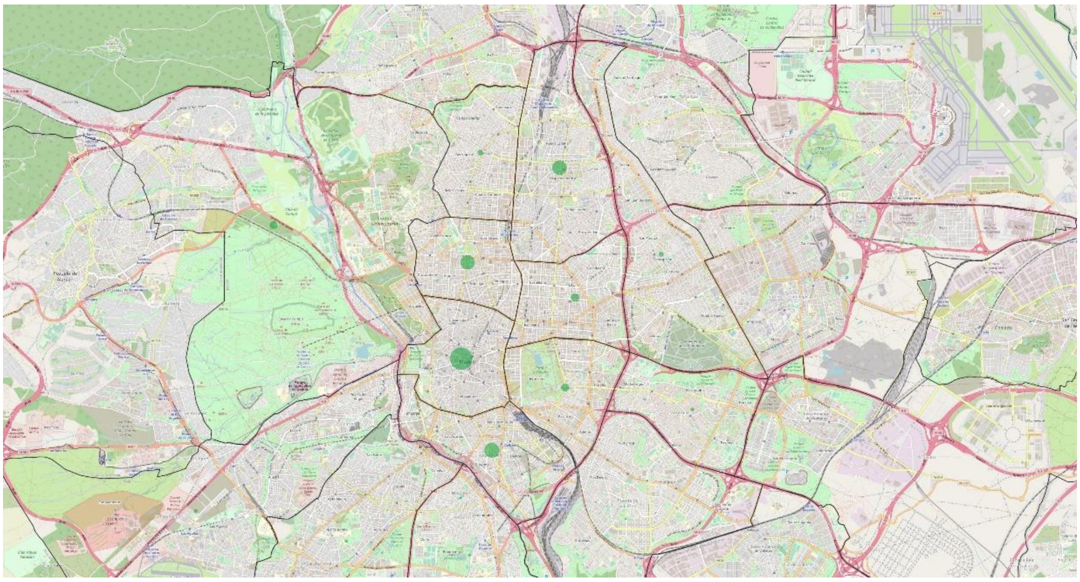

Figure 43: Destination districts of last-mile trips on weekends from BiciMAD station 252

The barrios to which the weekend last-mile trips end are shown in *Figure 44*. The central districts and barrios are the destination for most of these trips.

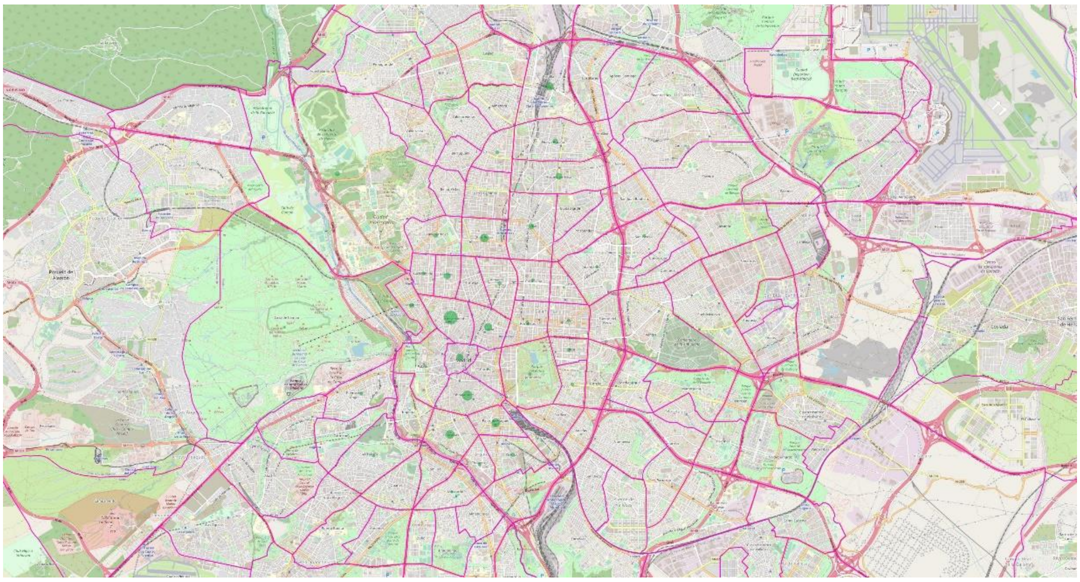

Figure 44: Destination barrios of last-mile trips on weekends from BiciMAD station 252

4.3.3 Analysis of popular routes to/from station 252

The analysis of the most popular route to/from station 252 is presented in this section. *Figure 45* shows the hourly ridership of first-mile trips during weekdays from stations 208/209 and station 245 to station 252.

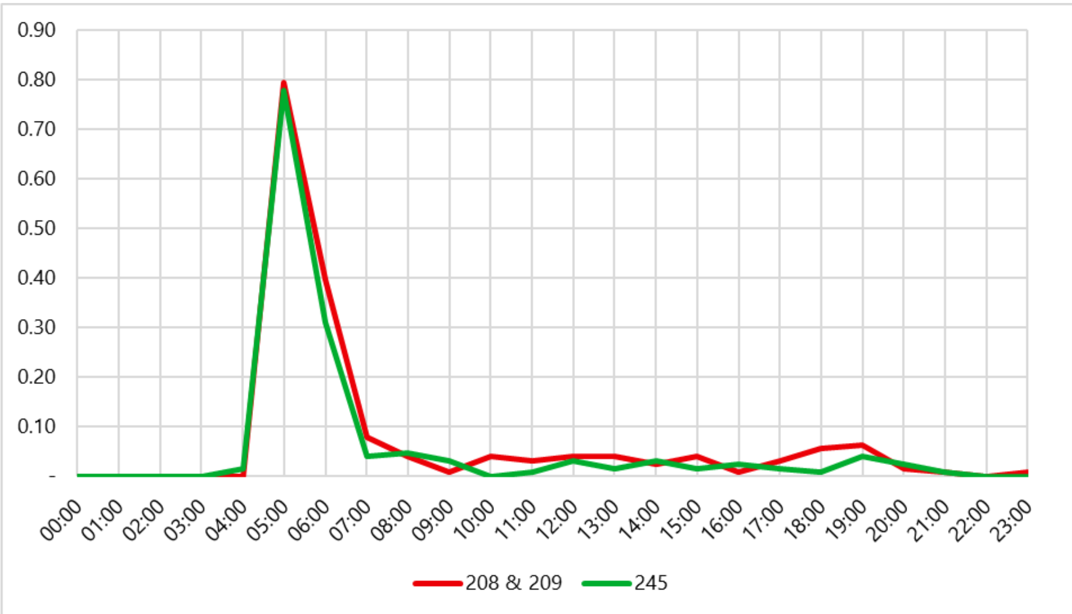

Figure 45: Average hourly ridership from BiciMAD stations 208 & 209 and station 245 during weekdays for first-mile trips ending at BiciMAD station 252

The hourly average of last-mile trips during weekdays from station 252 to stations 208/209 and station 245 is shown in *Figure 46*.

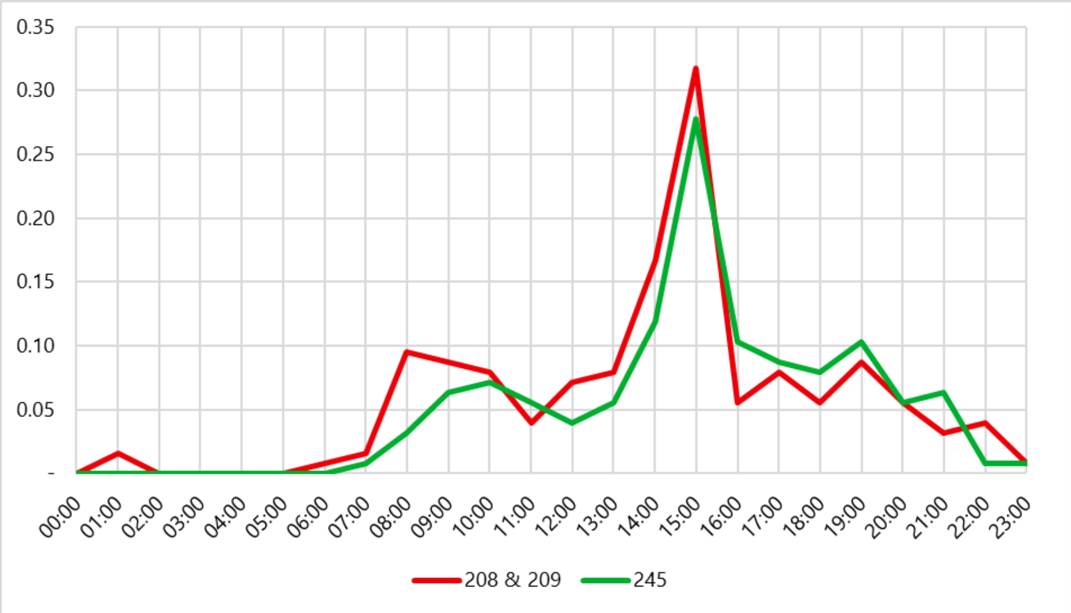

Figure 46: Average hourly ridership to BiciMAD stations 208 & 209 and station 245 during weekdays for last-mile trips starting at BiciMAD station 252

The hourly averages of first-mile trips happening from stations 208 & 209 and station 245 to station 252 during the weekends are shown in *Figure 47*.

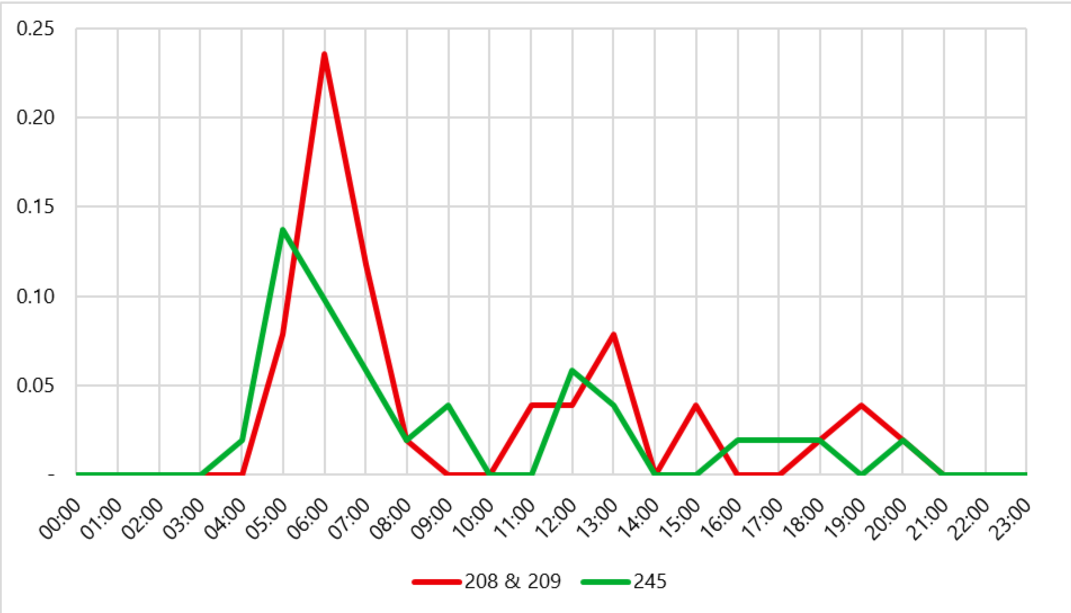

Figure 47: Average hourly ridership from BiciMAD stations 208 & 209 and station 245 during weekends for first-mile trips ending at BiciMAD station 252

The hourly averages of last-mile trips from station 252 to stations 208 & 209 and station 245 during the weekends are shown in *Figure 48* below.

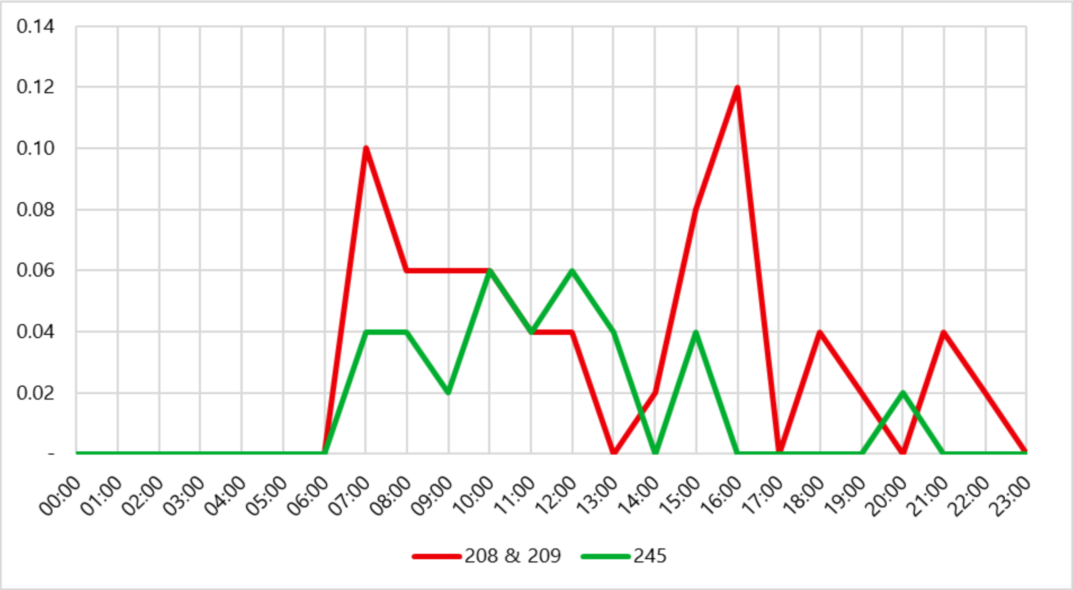

Figure 48: Average hourly ridership to BiciMAD stations 208 & 209 and station 245 during weekends for last-mile trips starting at BiciMAD station 252

4.3.4 Impact of station 252 on stations 208 & 209

The results of the comparison of the hourly ridership changes between November 2020 and March 2021 in stations 208 & 209 after the installation of station 252 are presented in this section. The change in ridership for the weekday first-mile trips is shown in *Figure 49*.

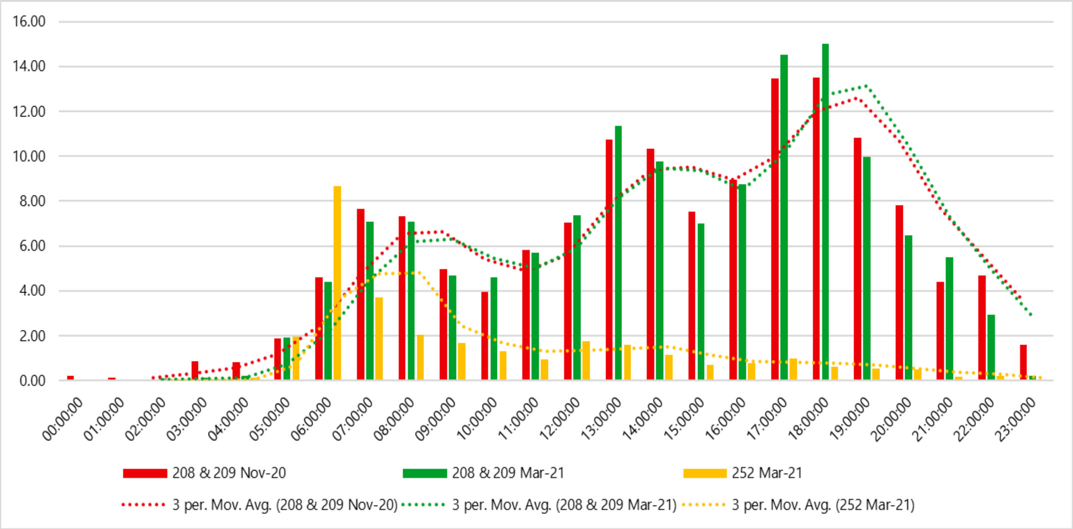

Figure 49: Change in ridership per hour during weekdays for first-mile trips ending in stations 208 & 209 between November 2020 and March 2021

The change in ridership for the weekday last-mile trips between November 2020 and March 2021 in stations 208 & 209 after the implementation of station 252 is shown in *Figure* 49 below.

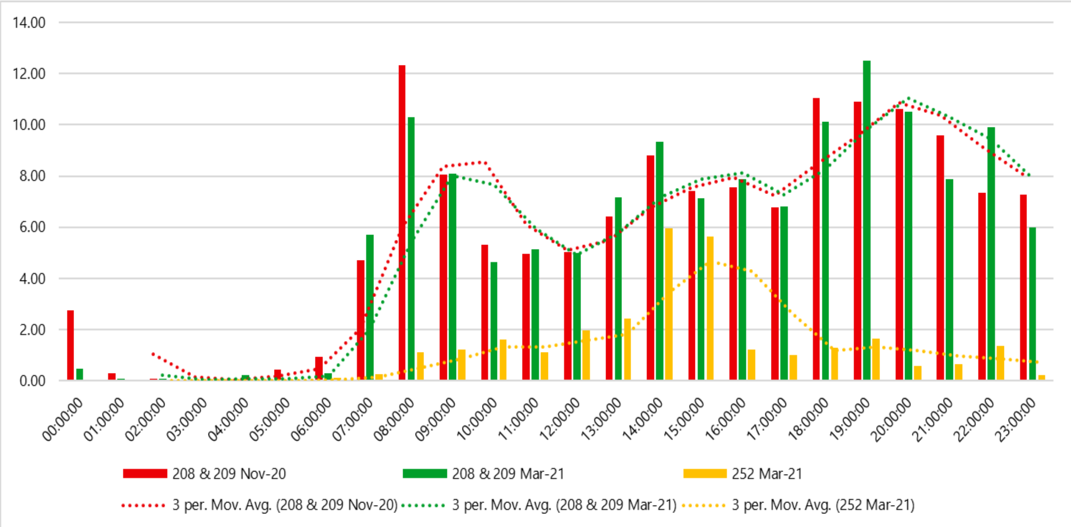

Figure 50: Change in ridership per hour during weekdays for last-mile trips beginning from stations 208 & 209 between November 2020 and March 2021

The change in hourly ridership during the weekends at stations 208 & 209 are shown in *Figure 51* and *Figure 52*. *Figure 51* below illustrates the shift in weekend first-mile ridership for stations 208 & 209 from November 2020 to March 2021 after the installation of station 252.

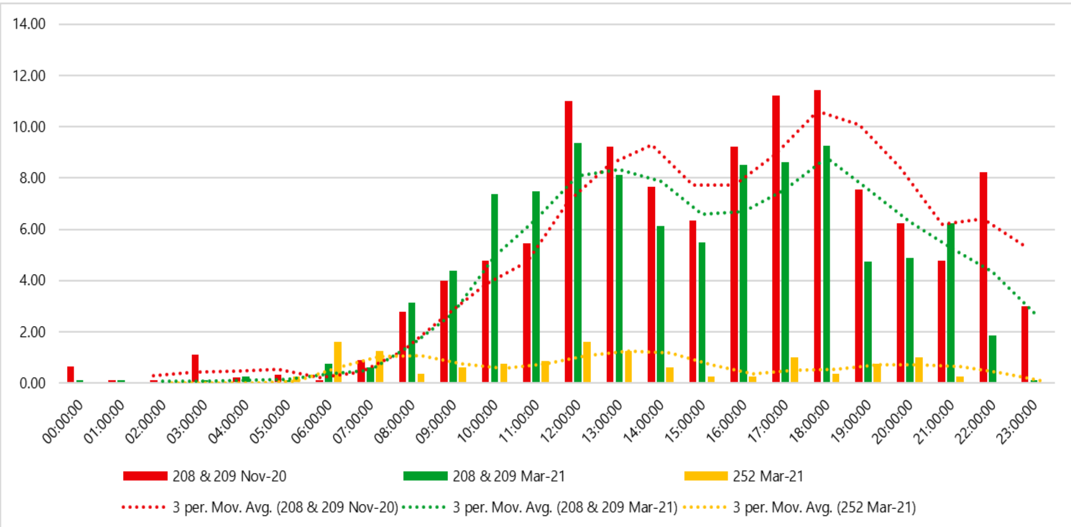

Figure 51: Change in ridership per hour during weekends for first-mile trips ending in stations 208 & 209 between November 2020 and March 2021

The change in weekend last-mile ridership ending at stations 208 & 209 between November 2020 and March 2021 is shown in *Figure 52* below.

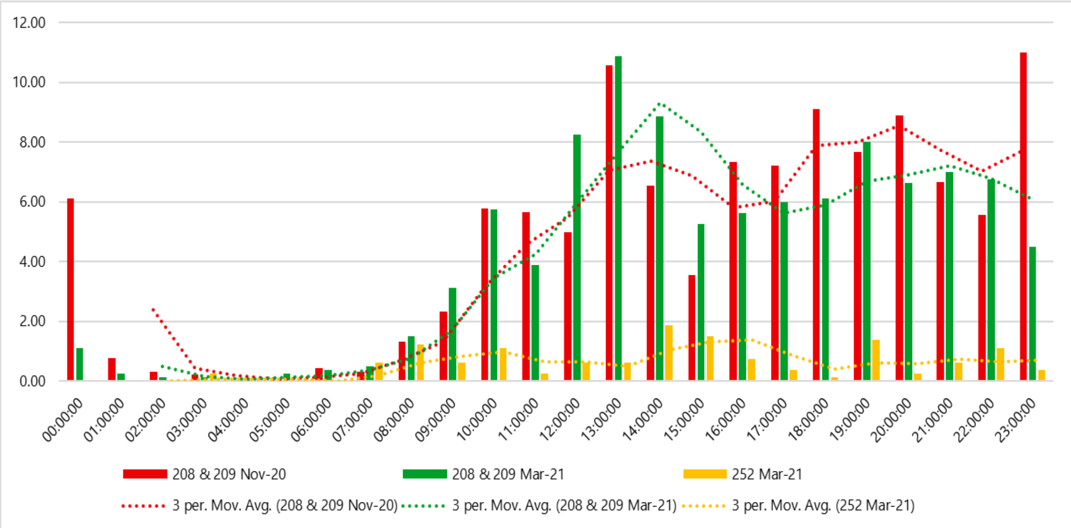

Figure 52: Change in ridership per hour during weekends for last-mile trips beginning from stations 208 & 209 between November 2020 and March 2021

5 Discussion

There are several intriguing observations revealed by the travel patterns seen at the twelve BiciMAD stations close to the Chamartín railway station, especially for trips done during the weekdays. Except for station 252, it is obvious that all twelve BiciMAD stations see their peak levels of ridership during two periods of the day which are the morning and evening rush hours. This is true for both first-mile and last-mile trips done during a weekday.

Station 252 is unique from other stations in that its peak ridership only occurs during morning rush hour for first-mile trips and evening rush hour for last-mile trips. It could be the case that some of the commuters may be using BiciMAD bikes to get to Chamartín station in the morning, then take a train to their destination to get to work. After work, they might return to Chamartín station and take a BiciMAD bike home from there. This intermodal trip chain involving BiciMAD station 252 in Chamartín railway station is illustrated in *Figure 53* below.

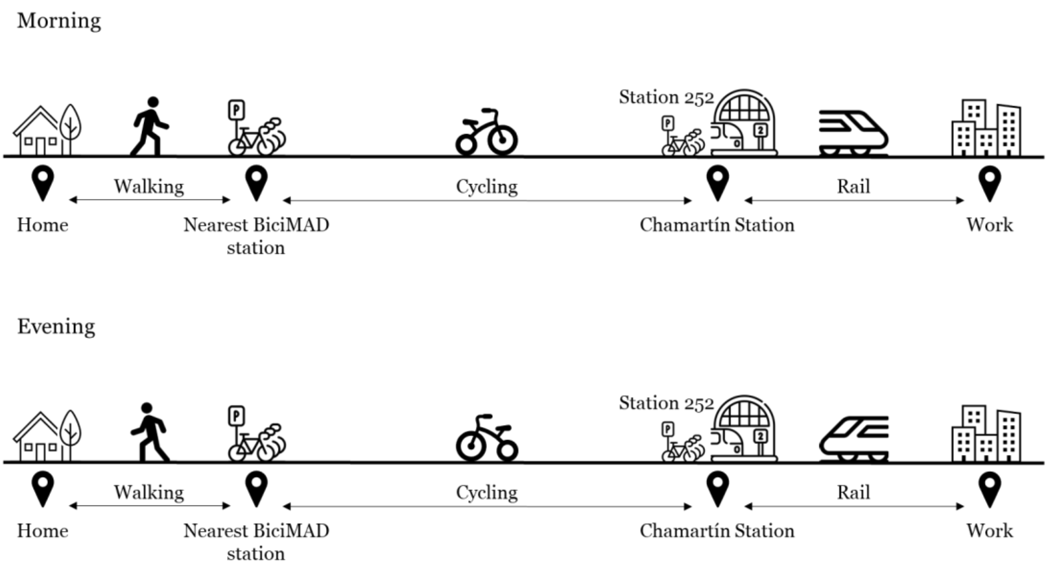

Figure 53: An intermodal trip chain identified involving BiciMAD station 252 (Own elaboration)

To verify the existence of such an intermodal trip chain, the trips happening between station 252 and station 245 were analysed. Station 245 is chosen since it has the highest number of first-mile and last-mile trips to station 252 throughout the weekdays. There were a total of 74 instances during weekdays between February 2021 and June 2021 where the same user had travelled from station 245 to station 252 during the morning peak hours and did the return journey during the evening peak hour. These first-mile and last-mile trips had an average time difference of almost 10 hours, which could mean that the user commuted further for work from Chamartín station.

The hypothesis that BiciMAD station 252 has been used for intermodal trips through Chamartín railway station is confirmed further by taking a closer look at the patterns in five other nearby BiciMAD stations (208, 209, 217, 248, 249). All these five stations have more than one distinct peak during a weekday, unlike station 252. The first-mile and last-mile trip patterns during weekdays mirror each other in the case of station 252, which is not the case for any of the other stations close by. This could be due to the same set of commuters using station 252 in the morning and evening while commuting for work.

The majority of the first-mile trips that conclude at station 252 in the morning on workdays originate in the Centro district, specifically in the Embajadores and Universidad barrios. The same holds for last-mile trips as well. The barrios of Embajadores and Universidad are where the majority of last-mile trips on weekdays conclude too. The Centro district is well connected with the Madrid Metro, but not that much with the commuter trains or Cercanias, which may be the reason for the higher number of BiciMAD trips between Centro district and Chamartín station.

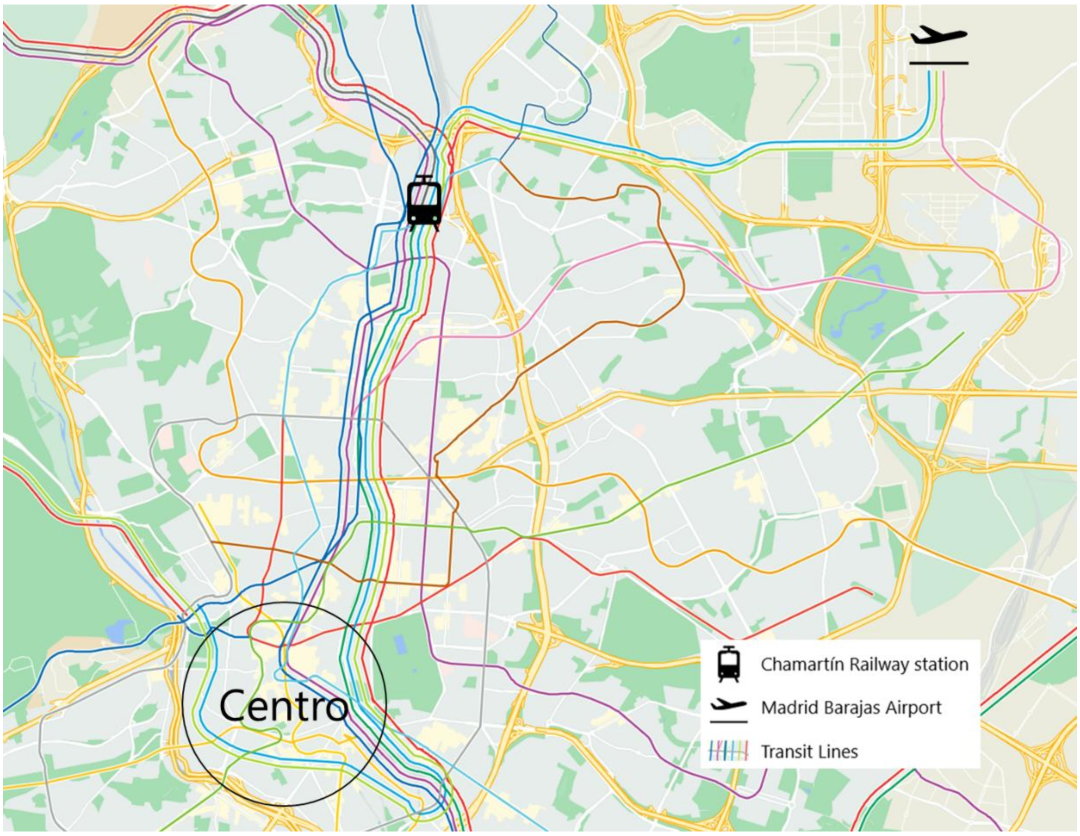

Figure 54: Transit lines from Chamartín station (Google Maps, 2022)

The Chamartín station serves as a point of entry to Madrid commune's northern areas through the Cercanias lines. It is important to note that the BiciMAD network doesn't extend beyond the Chamartín. Therefore, it is not surprising that people from the centre of Madrid utilize BiciMAD bikes to go to the network's periphery in Chamartín before switching to the Cercanias line for longer commutes. For example, if someone from Centro is working in Madrid's main airport located in Barajas, one way to commute is to take BiciMAD to Chamartín station and take a commuter train from there. This could be an explanation for the high number of BiciMAD trips between Centro and Chamartín during peak hours.

The absence of comparable peak demand patterns on weekends should serve as more evidence that the trips ending/beginning at station 252 during the weekdays may be part of the user's commute to work rather than leisure. It's also crucial to note that this analysis was conducted using data from frequent users or yearly pass holders of BiciMAD. This could be further evidence that some people regularly use bikes to access Chamartín station throughout the workweek, possibly to continue their commute to work locations in the northern parts of Madrid using the train.

Also, it is interesting to note that the travel patterns observed in BiciMAD station 252, don't support conventional wisdom. Usually, people move into the business districts in the city centre from residential suburbs in the morning, and they leave the city centre in the evening. The first-mile and last-mile trip patterns during weekdays in station 252 imply that people are moving away from the city centre in the morning and returning in the evening. There aren't many trips happening from station 252 in the morning or trips ending there in the evening.

Chamartín station acts as a gateway to Madrid from the northern suburbs, but commuters arriving there in the morning are not using BiciMAD from station 252. This may be because the BiciMAD network doesn't extend beyond Chamartín and it doesn't make sense for commuters from the suburbs who come to Madrid for work to have a regular/annual pass for a service that isn't offered where they live. Also, it is more convenient for them to make use of integrated public transportation tickets that allow them to use the same ticket for travel in public transport within the Madrid region (CRTM, 2022).

The comparison of the hourly ridership data at BiciMAD stations 208 and 209 between November 2020 and March 2021 does not offer any insightful information about how the opening of station 252 in Chamartín train station changed the intermodal travel patterns. The hourly averages of the first-mile BiciMAD trips ending at stations 208 & 209 between 6-10 am during weekdays have reduced. Although this is also coincidentally the busiest period of the day for trips ending at station 252, it cannot be conclusive evidence that the reduction in ridership at stations 208 & 209 was due to station 252. This is because, during other times on the weekdays, neither the trips ending at these stations nor the ones beginning at them exhibit any comparable drops in ridership.

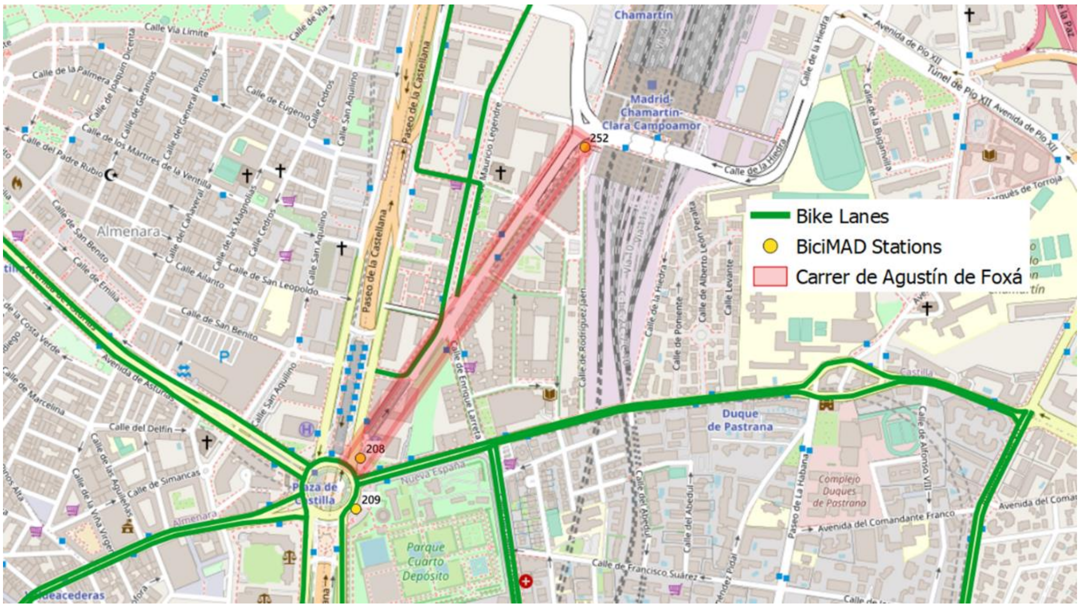

Figure 55: Dedicated bike lines near Chamartín station (Madrid City Council, 2022)

A reduction in hourly averages at stations 208 & 209 may be expected since the BiciMAD users who previously used these stations to access or egress the Chamartín railway station will now be using station 252 to end or begin their rides. As explained previously, this is not the case and one of the possible reasons for this may be because Carrer de Agustín de Foxá which connects Chamartín station and Plaza Castilla, where stations 208 & 209 are located, doesn't have a dedicated bike lane as shown in *Figure 55* and *Figure 56*. As reviewed in the literature, this is one of the significant hindrances for people not using bikes (Guo & He, 2020).

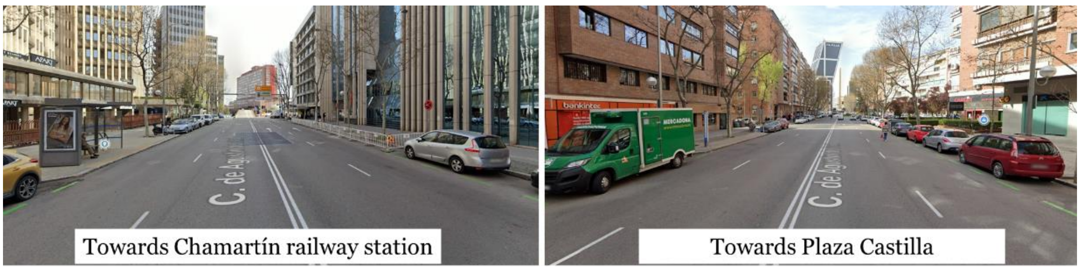

Figure 56: Carrer de Agustín de Foxá connecting Chamartín station and Plaza Castilla (Google Street View, 2022)

It is crucial to have a safe bike lane that is segregated from other vehicles while evaluating the possibilities to promote better integration of BiciMAD with public transportation at Chamartín station. This is one of the initiatives under the #ChallengeMyCity project in Madrid. With a safer route between Plaza Castilla and Chamartín station for cyclists, the number of people using bikes to access or egress Chamartín station may increase. The impact of such implementations will be quantified by the end of the project for scaling up in the future.

Another approach that could encourage rail users in Chamartín station to use BiciMAD in their first and last mile of the trip is to have an integrated ticketing system that allows users to use the same ticket for public transport and BiciMAD. Integrated ticketing systems for public transit and micromobility are expected to enhance the user experience and make the transfer between the modes more efficient (Böcker et al., 2020).

5.1 Limitations of the Study and Future Research

Although all publicly available data were used in the analysis, there are still certain gaps that warrant further investigation. The network as a whole is not evaluated; the thesis mainly focuses on the influence on the hourly ridership at the BiciMAD stations close to Chamartín railway station. Additionally, to comprehend the mode choice, type of commuting (work/leisure), socio-demographic characteristics etc., a user survey to confirm the results of the data analysis was required.

For station 252, just the first six months of data are analyzed because the rest are not available in the public domain. This might not paint a complete picture of the long-term effects of station 252 on commuters' mode preferences. Future data analysis studies should be conducted for a larger data set and a user survey needs to be conducted concurrently.

Except for the significant meteorological occurrence of Storm Filomena, local issues like the impact of weather, like rain or higher temperature, on ridership were not taken into account. Also, this thesis does not quantify the environmental impact of the BiciMAD network's extension to the Chamartín station region. This holds for social and economic effects as well, such as access to opportunities, which are not examined in this thesis.

The study hasn't looked at other options which are available for access and egress at Chamartín railway station. Future research should examine how the market is rapidly changing and whether BiciMAD usage has any ties to other established or new forms of transportation, such as car sharing and other shared micromobility choices, such as electric scooters for access and egress.

Finally, as for the #ChallengeMyCity project, the impact of the initiatives undertaken at Chamartín in Madrid, Matabiau in Toulouse and Rogoredo in Milan will be quantified at the end of the pilots in early 2023. The methodology explained in this thesis could be used to determine the number of intermodal trips happening in each of these locations as a result of installing new micromobility solutions there. Also, through a user survey, the modal shifts from private cars to micromobility happening in the first/last mile of public transport journey at these three stations need to be determined.

In addition, for future #ChallengeMyCity projects with longer timelines, the environmental and social impact of the initiatives need to be quantified. Learnings from the current project, facilitating better integration with a focus on first and last-mile transportation are essential to scale up future implementations at other public transport hubs in different cities.

6 Conclusion

Micromobility—both privately owned and shared—has emerged as a key instrument for cities that are looking to transition to sustainable urban mobility. The advances in technology had breathed a new life into the role it had played in the mobility ecosystem of our cities. By improving the access to public transport, micromobility plays a crucial role in fixing the first or last mile problem associated with public transport. This, not only, helps in increasing access to opportunities for a larger section of the population but also has the potential to disrupt the use of private cars and facilitate modal shifts towards public transport (Thomas Holm Møller & John Simlett, 2020).

To promote intermodality between public transport and micromobility, cities are taking up many projects. One such initiative is the #ChallengeMyCity project in Milan, Toulouse, and Madrid. In these cities' key public transportation hubs, like Rogoredo in Milan, Matabiau in Toulouse, and Chamartín in Madrid, several initiatives are being made to promote intermodality between public transportation and micromobility, such as bike parking places, safe bike lanes to access the stations, etc. These implementations will be assessed for their socioeconomic and environmental impacts at the project's conclusion in late 2022, which will assist in scaling them up.

Within this context of intermodality between micromobility and public transport, this thesis has examined the elements that provide seamless integration of public transportation and micromobility. A systematic review of the literature was done to determine various factors that facilitate the use of micromobility to access or egress public transport.

The availability of infrastructure that facilitates the safety and comfort of micromobility users is considered important in influencing commuters of public transport to use micromobility for access and egress. Furthermore, promoting dense, interconnected communities with diversified land uses, as well as pedestrian and bicycle-friendly neighbourhoods are recommended to induce modal shifts in favour of sustainable modes.

In the literature, policies that support both the creation and application of micromobility have been identified as critical interventions. Additionally, it is advised that while developing shared micromobility systems to complement the public transportation network, all relevant stakeholders be included from the very beginning. This can help in promoting the use of micromobility as well as in its integration with public transport.

A considerable improvement in the shared micromobility systems' integration with public transportation has been highlighted thanks to the role of technology in giving users access to real-time information and enhancing the systems' usability. Additionally, technology aids the operator in optimizing the redistribution of micromobility devices based on demand, which ensures availability and encourages the use of micromobility.

Finally, it has been discovered in the literature that a variety of price structures and incentives have a favourable impact on the adoption of micromobility to access or egress public transportation. It has been highlighted that integrated ticketing, discounts for a variety of user groups, rides during off-peak hours, loyalty programs etc., have made intermodality with public transportation easier.

After the literature review, data analysis from a previous micromobility installation in one of the #ChallengeMyCity project locations was carried out to test the hypothesis that the installation of micromobility solutions near a public transport hub induces intermodal transport involving public transport. The case involved the expansion of Madrid's BiciMAD public bike-sharing program to the Chamartín railway station, where a new BiciMAD docking station was set up outside the station. There is evidence to suggest that commuters had used BiciMAD to access public transportation through Chamartín railway station, especially for work on weekdays using the new station. But, its impact is limited due to Chamartín railway station not being connected by a safe bike lane from the nearby Plaza Castilla.

Future studies should be complemented with a user survey to understand commuters' mode choices, type of commute, socio-demographic characteristics etc over a longer period. Also, it is important to look into the correlation of public-bike sharing systems with other shared modes of transport such as car-sharing, especially in the first or last mile, for accessing public transport. The long-term socio-economic and environmental impacts of initiatives, such as #ChallengeMyCity, to support intermodality between micromobility and public transport need to be studied in depth.

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ANNEXURE - 1

```
import pandas as pd
import numpy as np
import math
import dateutil.parser
from pandas.io.json import json_normalize

start_time = time.time()
# Data describing all bike rides
BIKE_RIDES_DATASET = 'C:/Users/malik/OneDrive - EIT Urban Mobility/Work/Challenge My City/Thesis/Python/Bicimad_Movements/2021/202106_Usage_Bicimad.json'
# Data describing all stations (used just for getting stations' coordinates & names)
STATIONS_DATASET = 'C:/Users/malik/OneDrive - EIT Urban Mobility/Work/Challenge My City/Thesis/Python/Bicimad_Stations/202106.json'

df = pd.read_json(BIKE_RIDES_DATASET, lines=True, encoding="latin-1")

# getting the data for specific station ID. Just change the number after == to station ID you need.
df_station_x = df.loc[df['idplug_station'] == 252]
# Following line convert the dataset to csv. You could open it in Excel. The csv file will be saved where you have this python code on your computer.
df_station_x.to_csv('Jun_2021_252.csv', index = False)
```