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On the path to develop a micromobility journey planner for Madrid: A tool to estimate, visualize, and analyze cycling and other shared mobility services' flow

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Abstract: Journey planners could be one of the most relevant aspects to consider when choosing and deciding our daily trips. However, many of these trip apps still do not consider the new forms of mobility that are emerging in cities, also known as micromobility services (shared bikes, mopeds and scooters). In this study, we pursue two main objectives. On one hand, we create a journey planner for micromobility in Madrid. On the other hand, we use the journey planner to estimate and analyze micromobility flow considering the origin and destination points of trips registered in 2019 from the three different shared modes. Our results involve a series of maps that illustrate how micromobility flow is distributed in the city and the different dynamics considering two scenarios (weekdays and weekends). The journey planner helps to visualize those streets where micromobility flow concentrates, making micromobility users more visible and thus promoting that their paths become safer, attracting new users to start using micromobility (positive loop). Also, the maps could help policy planners to allocate new infrastructure in the city where it is needed most.

Keywords: Route map, journey planner, bike, moped, scooter, micromobility

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1 Introduction

Since their introduction in the 60s, bike-sharing systems have been consolidated as one of the most important strategies to reduce CO_2 emissions in urban areas. More recently, other shared modes have arisen in cities, like mopeds (also known as moped-

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style scooter-sharing) and scooters (also known as kick-style scooter-sharing). These new forms of mobility are being incorporated into the new mobility ecosystem as new travel choices that citizens now have, when planning their trips. One of the most important aspects for planning and choosing a travel mode is to have real-time, useful, and trustful information, which is mostly offered through journey planners. However, these journey planners usually consider only public transport systems and the traditional modes that have been operating for decades, leaving these recently introduced new forms of mobility outside the options. The aforementioned modes are changing the mobility paradigm, putting the focus on transitioning from a car-oriented development into a proximity one. However, from a technological point of view, they are not being considered by most of the available trip planning applications.

Many studies delved into the topic of journey planners (Arbeláez Vélez, 2023; Broach et al., 2012; Chen et al., 2023; Fiorini et al., 2022; Hochmair, 2005; Hoobroeckx et al., 2023; Hrncir et al., 2014; Liu et al., 2022; Scott et al., 2021; Su et al., 2010; Tal et al., 2013; Tscharaktschiew & Müller, 2021; Turverey et al., 2010; Wortmann et al., 2021; Zhang et al., 2021; Zhang & Zhao, 2022) (see Table 1), but only a few studies relate to the proposition of innovative journey planners that offer shared micromobility options. One of these studies is (Georgakis et al., 2020), which proposed a MaaS (Mobility as a Service) journey planner, but apart from traditional modes (private car and public transport) it only considers bike-sharing, ride-hailing and car-sharing, not taking into account other shared modes like mopeds or scooters. In (Amrani et al., 2020), the authors innovated by introducing machine learning models to forecast trains and stations' occupancy, offering additional and useful information for users, but again, the only micromobility service considered was bike-sharing. In the case of (Yu et al., 2015), the authors proposed a journey planner called "JPlanner" for the city of Singapore, which considered the private car and public transport options as well as park-and-ride facilities, taxi services, bike-sharing and walking. Other studies designed journey planners for specific users, reaching a specific market segment. One of these studies is the innovative approach taken by (Nurminen et al., 2020) as they proposed a journey planner for Helsinki suited specifically for pedestrians that want to avoid routes with high air pollution. Another study is (McCarthy et al., 2019) which developed a journey planner for the vision-impaired community. These kinds of solutions designed for specific users and considering relevant variables for them are necessary in the new mobility ecosystem, which is demanding more specialized services.

Table 1. Studies on the topic of journey planners

Year	Author(s)	Title	Findings
2005	Hochmair	Towards a Classification of Route Selection Criteria for Route Planning Tools	The authors proposed a journey planner that decides between fast, safe (least interaction with traffic), simple, attractive, and short. They assigned weights to each variable based on survey responses.
2010	Turverey et al.	Charlottesville Bike Route Planner	The authors proposed a web-based journey planner with two options: safe and efficient routes. They used the following weights: Safety(40% of total score): -Width of Road(.077) -Presence of Bike Lane(.059) -Passes through Intersection (.069) -Speed Limit(.060) -Road Conditions (.064) -Traffic Density (.071) Distance(60% of total score): -Distance Travelled (.60)
2010	Su et al.	Designing a route planner to facilitate and promote cycling in Metro Vancouver, Canada	The authors designed a web-based journey planner with the options: shortest path route, restricted maximum slope, least elevation gain, least traffic pollution and most vegetated route. Their planner returns: route length (km), estimated time (min), CO2 prevented (Kg), Calories burned (cal), Mean No2 concentration (ppb), total elevation gain (m) and mean vegetation cover (%). .
2012	Broach et al.	Where do cyclists ride? A route choice model developed with revealed preference GPS data	Based on GPS routes from 164 cyclists the authors estimated the most important factors for route choice: distance, turn frequency, slope, intersection control (e.g., presence or absence of traffic signals), and traffic volumes, infrastructure: off-street bike paths, enhanced neighborhood bikeways with traffic calming features (aka “bicycle boulevards”), and bridge facilities.
2013	Tal et al.	eWARPE – Energy-efficient Weather-aware Route Planner for Electric Bicycles	Using historical data, they proposed a router planner that returns the most convenient time for the cyclist to leave from point A to B avoiding adverse weather conditions and saving battery life on their electric bike. Variables considered: air density, speed, wind speed, slope, total weight (cyclist, bicycle and accessories) and wind direction.
2014	Hrncir et al.	Bicycle Route Planning with Route Choice Preferences	The authors made a revision of the most popular journey planners and their features: •OpenTripPlanner: allows preferences (time and slope) and considers the shortest path. •CycleStreets: offers mean speed and returns the fastest, quietest and a balanced route. •BBBike: returns the shortest route, road Surface, Street category and avoidance of unlit streets. The paper proposes a journey planner that considers four profiles: commuting, bike friendly, flat y fast. Based on these 4 profiles and using the cost function they offer information about: travel time, comfort, quietness y flatness.

Table 1. Studies on the topic of journey planners

Year	Author(s)	Title	Findings
2020	Georgakis et al.	Heuristic-Based Journey Planner for Mobility as a Service (MaaS)	They proposed a prototype journey planner for MaaS offering. The journey planner is fed by external APIs and filters routes according to users' declared preferences: For users without a driving license, routes with modes that require driving are excluded. Routes with long bicycle distances (as defined by the user) are excluded. Routes with long walking distances (as defined by the user) are excluded. Routes with services for which a user does not have any allowances left (i.e., minutes left for carsharing service). They worked with pre-stablished modal chains: (1) Bike-sharing from origin to destination (2a) Bike-sharing to public transport (2b) Public transport to bike sharing: cycling distance (min) 0.3, cycling/overall route distance ratio (min) 0.3, public transport modal changes (min) 0,15 and public transport modal speed (max) 0.25. (3) Car-sharing from origin to destination (3a) Car-sharing to public transport (3b) Public transport to car-sharing (4) Ride-hailing from origin to destination (5a) Ride-hailing to public transport (5b) Public transport to ride hailing
2021	Tscharaktschiew & Müller	Ride to the hills, ride to your school: Physical effort and mode choice	The authors aim to understand the substitution between bicycling and public transport in school travel focusing on the personal effort (in terms of kcal) of students when traveling by bike (or walk). Their results show that in terms of effort, the widespread adoption of bikes in school travel could have only limited impacts on peak-period public transport demand.
2021	Scott et al.	Route choice of bike share users: Leveraging GPS data to derive choice sets	The study develops models that models that suggest that Hamilton Bikeshare users are willing to detour for some attributes, such as bicycle facilities, but tend to avoid circuitous routes, turns, steep slopes, and roads with high traffic volume.
2021	Zhang et al.	What type of infrastructures do e-scooter riders prefer? A route choice model	The authors developed an e-scooter route choice model to reveal riders' preferences for different types of transportation infrastructures, using revealed preferences data They results show that e-scooter riders are willing to travel longer distances to ride in bikeways (59% longer), multi-use paths (29%), tertiary roads (15%), and one-way roads (21%). E-scooter users also prefer shorter and simpler routes. Finally, slope is not a determinant for e-scooter route choice, likely because e-scooters are powered by electricity.
2021	Wortmann et al.	Analysis of electric moped scooter sharing in berlin: A technical, economic and environmental perspective	The authors investigate the ability of an e-moped sharing system to substitute passenger car trips. The results indicate that a substantial part of all passenger car trips in Berlin can be substituted. The larger the fleet, the more and longer trips are replaced.
2022	Liu et al.	Understanding the route choice behaviour of metro-bikeshare users	The authors analyzed the route choice behavior of metro-bikeshare users considering passengers' socio-economic attributes and perceived congestion which is approximated by load. Over-crowding in the metro system resulted as a relevant variable for route choice. As well as other variables like transfer penalty factor, in-vehicle travel time, out-vehicle travel time, the number of shared bike stations, the number of docks, user's gender, and travel departure.
2022	Fiorini et al.	On the adoption of e-moped sharing systems	The study explores the hypothesis that the adoption of electric mopeds depends on the built environment and demographic aspects of each neighborhood. Their results validate the initial hypothesis and shows that communities within a city tend to aggregate by wealth and isolate themselves from one another as very few interactions, in terms of trajectories, have been observed between the richest and poorest areas of the city under study.

Table 1. Studies on the topic of journey planners

Year	Author(s)	Title	Findings
2022	Zhao, P., Yuan, D. and Zhang, Y.	The Public Bicycle as a Feeder Mode for Metro Commuters in the Megacity Beijing: Travel Behaviour, Route Environment, and Socioeconomic Factors	The study explores the intermodality between bike-sharing systems as feeder mode. The results showed that middle-aged and medium-income commuters are more likely to use public bicycles as a feeder mode for metro transport. The built environment had significant effects on public bike use. Most of the cyclists preferred cycling routes with high directness, while high-income and high-education cyclists viewed comfort and safety of the trip as priority factors. Most trips were within 2 km, and a longer travel distance was significantly related to a higher possibility of public bicycle use.
2023	Chen et al.	Exploring electric moped sharing preferences with integrated choice and latent variable approach	The study explores individual preferences toward the shared moped services using stated preference data. The impacts of latent variables like advocacy for the service, hedonic motivation, and attitudes toward the service varied in the groups with and without past riding experience, providing insights into the service adoption. The group aged below 30 revealed high uptake toward shared e-mopeds.
2023	Arbeláez-Vélez	Environmental impacts of shared mobility: a systematic literature review of life-cycle assessments focusing on car sharing, carpooling, bike-sharing, scooters and moped sharing	The study presents a literature review of shared mobility and its environmental impacts. Factors that influence changes in environmental impacts are travel behavior, the design of shared mobility modes, and how such schemes are implemented, as well as the local context.
2023	Hoobroeckx et al.	Travel choices in (e-)moped sharing systems: Estimating explanatory variables and the value of ride fee savings	The authors study the adoption factors for mopeds. Results show that relevant variables are vehicle availability, pricing, trip characteristics, and socioeconomic factors.

Source: own elaboration

Similarly to these group of studies, our work aims to contribute to the literature that innovates in the journey planner topic, by integrating different micromobility modes (bikes, mopeds and scooters), offering alternative routes to the shortest path (considering more than just time or distance costs) and targeting a specific group of people (in our case, cyclists and micromobility users) to adapt as much as possible to their needs and achieve a higher adaptation rate.

2 Objectives

Therefore, our paper pursues two main objectives. On the one hand, we create a journey planner for micromobility in Madrid. On the other hand, we use this journey planner to estimate and analyze micromobility flow registered during 2019 from the three different shared modes (bike, moped and scooter). To conduct our study, we used as input information, the origin and destination points of each trip made by each service (GPS records). As the trip track (or route) is not available (only trip origin and destination), we test the journey planner by estimating routes using two different approaches: for mopeds, we used the shortest path with the Dijkstra’s algorithm (based on time cost), and for bikes and scooters we created what we called the “friendly” route that considers not only distance or time costs, but also the slope of streets, the presence and type of cycling infrastructure, the characteristics of existing motorized traffic and trees’ density. After obtaining the estimated routes, we elaborate a map which illustrates the micromobility services’ flow at street level. Apart from considering different modes, we also consider different dynamics according to the day of the week (weekdays and weekends). This information is vital for allocating new micromobility infrastructure, or for implementing local policies or measures, where they are really needed, according to the existing demand, made visible through our maps. The journey planner also helps to visualze those streets where micromobility flow concentrates, making micromobility users more visible and thus promoting that their paths become safer, attracting new users to start using micromobility (creating a positive loop). The rest of the paper is divided into four sections. Section 3 introduces the case of study, while Section 4 describes the data and methods used. Section 5 offers results and discussion, and finally, in Section 6 we outlined the main conclusions of the work.

3 Case study

We consider Madrid as our case of study. Madrid has a multiple and varied shared mobility supply, great diversity of land use and high densities of population and employment with more than 6 million people in the Metropolitan Region, and half located in the Municipality of Madrid (Instituto Nacional de Estadística, 2018). The city is known to be a shared mobility living lab, which allows its residents to be familiar with the emerging transport options, especially micromobility services (Aguilera-García et al., 2020; Arias-Molinares et al., 2023). In 2019, the shared fleet was estimated at more than 20.000 vehicles(Arias-Molinares & García-Palomares, 2020). These services are usually supported by mobile applications where their clients register and locate the vehicles. In the case of Madrid, all micromobility services offer electric vehicles and can be station-based or dockless models. In this paper, we focus on three micromobility services (shared modes) operated by different operators: BiciMAD, which is Madrid's public and station-based bike-sharing system, and two private and dockless micromobility operators (see TableTable **2**). To access the anonymized trip databases, collaboration agreements were established with two of the most important micromobility operators in Madrid (Movo and Muving). In the case of BiciMAD, the data was publicly shared through their open data portal. Station-based services like BiciMAD, have designated locations where users pick and leave the vehicles at, while dockless services, like Movo and Muving, offer more flexibility as the vehicles can be picked/returned at any location within a geographic area (also known as geofence). In Madrid, bikes and scooters can circulate in all areas of the city (except pedestrian zones), while mopeds circulate and follow the regulations of cars. Moreover, all shared mobility vehicles are electric.

Table 2. Main characteristics of the three micromobility operators analyzed

Micromobility service	Operator	Modes included	Model	Operating since	Subscribers	Vehicles
BiciMAD	Public EMT Bus Company	Bike-sharing	Station-based	2014-today	75.000	2900 bikes 264 stations
MOVO	Private Cabify	Moped-style scooter-sharing Scooter-sharing	Dockless	2018-today	No info	500 mopeds 1.400 scooters
MUVING	Private Sharing Muving	Moped-style scooter-sharing	Dockless	2018-2020	31.934	755 mopeds

Source: own elaboration

4 Methodology

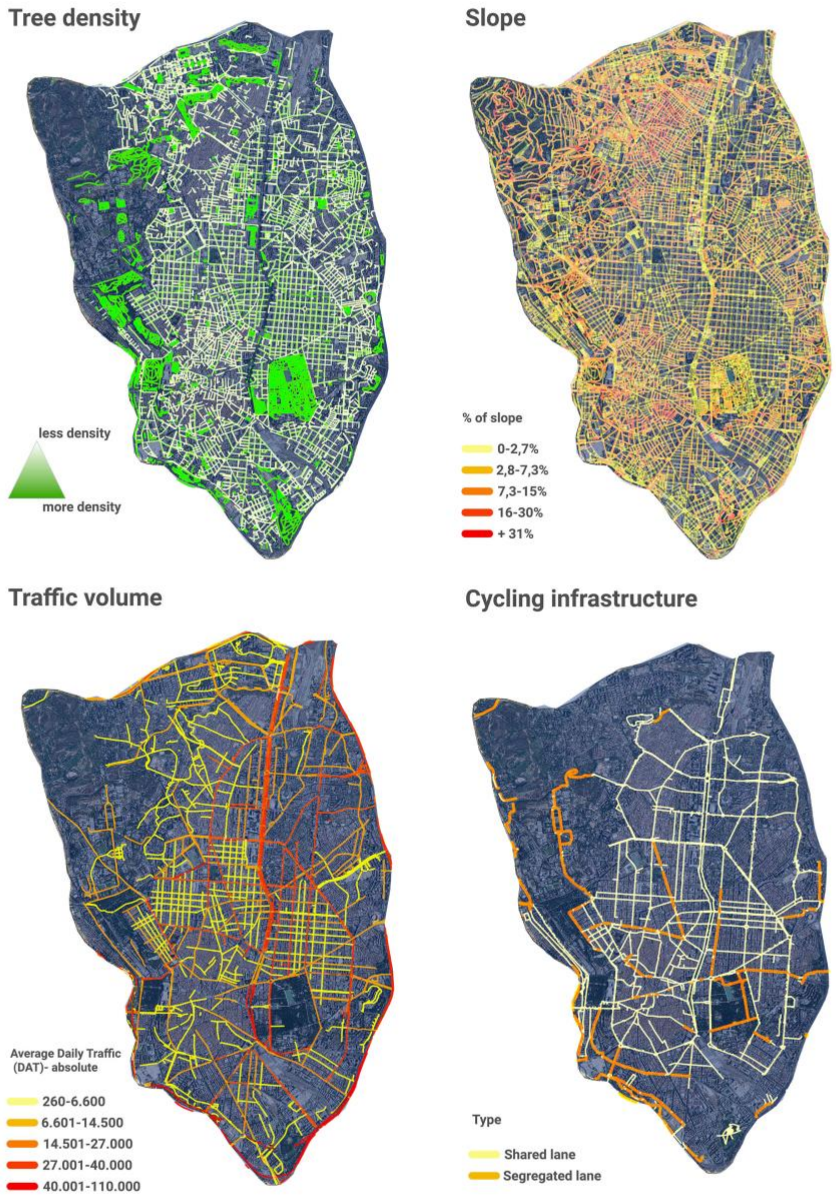
4.1 Journey planner creation

The first part of the study involves the creation of the journey planner. To this end, we use a built environment database with cartographic and statistical information from Madrid City Council's open data portal (https://datos.madrid.es/portal/site/egob). This database integrated a group of variables characterizing the city in terms of street slopes, traffic speeds, cycling infrastructure, bus lanes, tree density, etc. (see Table 3 and Figure 1).

Table 3. Variables collected to characterize the street network

Variable	**Description**	**Source**	**Values**
Street type	Type of street	Madrid's City Open Portal	1. street link, 2. Roundabout, 3. Lower passageway, 4. Upper passageway, 5. Intersection
Cycling infrastructure	Type of cycling infrastructure (segregated or shared lane)		1. Segregated bike lane, 2. Shared bike lane
Traffic flow	Average daily number of vehicles that transit the street segment		Number
Speed limit	Speed limit allowed in each street segment		Number
Slope	Average slope by street segment		Number
Street lanes	Number of lanes of each street segment		Number
Street lane width	Width of lanes in each street segment		Number
Bike lane width	Width of bike lane in each street segment		Number
Tree density	Presence or absence of tree classified by density (high, medium, low)		1. Yes- High , 2. Yes-Medium, 3. Yes-Low, 4. No

Source: own elaboration


Tree density

Slope

Traffic volume

Cycling infrastructure

Figure 1. Some of the variables considered in the study (tree density, slope, average daily traffic and cycling infrastructure)

After obtaining, cleaning and processing the built environment database, we created a street network in which each link of the network could have all the information about the street characteristics (built environment) using the "join table" tool in Arcgis Pro version 3.1 to join the information from different tables. The following process involved assuming that scooters and bikes share similar impedance determinants as they have equal regulation in terms of circulation and share the same infrastructure. While in the case of mopeds, they need to circulate as a car, and they also allow higher speeds (with respect to active travel modes like bikes and scooters). To that end, we proceeded to calculate two impedances: one for scooters and bikes and another one for mopeds. For scooters and bikes, we estimated cyclists' speed for each link, weighting distance according to different factors that impact active travel (bikes and scooters) mobility. To this end, we used a previous study conducted by (Romanillos, 2018) in which the author modelled cyclists' speed for Madrid using trip datasets. The study estimates cycling speed (si) for each link through an ordinary least squares (OLS) model that includes the explanatory variables included in Table 4. Considering this, the equation is:

$$s_i = \beta + SI\, x_{i2} + I\, x_{i3} + TL\, x_{i3} + BS\, x_{iTL} + SL\, x_{iTL} + NSB\, x_{iTL} + SB\, x_{iTL}$$

Table 4. Description of the explanatory variables included in the OLS model on cycling speed

Explanatory variables	Coeff. Value	Description
Intercept	13.90	Constant that represents the mean value of the response variable when all of the predictor variables in the model are equal to zero.
Street Intersections / km	-0.11	Calculated as the ratio of number of intersections per route segment (km).
Slope (percent rise)	-0.61	Slope in percent rise, estimated by calculating the elevation for each node of the GPS route segments from a high-resolution Digital Elevation Model (cell size = 5x5 meters).
Traffic Lights / km	-0.04	Considered as the ratio of number of traffic lights per route segment (km).
Bike lane on the sidewalk (dummy variable).	-0.76	Type of road regarding bike infrastructure according to the Madrid Cycling Master Plan classification.
Speed limit (kph)	0.02	Maximum traffic speed (kilometres per hour) per street segment, according to TomTom® database.
Non-segregated bike lane (dummy variable).	1.09	Type of road regarding bike infrastructure according to the Madrid Cycling Master Plan classification.
Segregated bike lanes in parks with a minimum adapted surface (dummy variable).	2.58	Type of road regarding bike infrastructure according to the Madrid Cycling Master Plan classification.

Source: own elaboration

With the traffic speeds and the length of each street link we were able to calculate the default impedances and the shortest path using the Dijkstra's algorithm for mopeds as they just can circulate on streets. However, once obtaining the cycling speeds we were able to calculate a new travel cost (TC_f) that will correspond to what we called the "friendly route." For the case of active travel modes like bikes and scooters that can circulate on streets but also on other types of spaces (such as green areas, etc.) we decided to estimate a "friendly route." This friendly route was calculated based on the coefficient included in the research carried out by Romanillos et al. (2012), considering a number of studies on the topic.

In this work, the author estimates "preferred routes" by cyclists considering other variables beyond time or distance (shortest path). This work analyzed how some people are willing to travel longer (distance) if they can use cycling infrastructure (especially segregated lanes) or move around green areas with nice scenery (timesaving is not the main criterion for choosing the route). Based on the analysis of other studies on the topic that analyzed preferences based on pairwise comparison, the work assesses how much these distances or perceived travel times are lengthened or shortened. Hence, for the case of scooters and bikes, we used the travel cost for friendly route (TCf), which was calculated for each link by multiplying the previously obtained speed (si) by its length (Li), and by the coefficients corresponding to the street type (βst), tree density (βtd) and the average daily traffic (βADT) (see Table 5), according to this equation:

$$TCf = (Li / si) \cdot \beta st \cdot \beta td \cdot \beta ADT$$

Table 5. Estimation of coefficients

	Street type	**βtv**
Estimation of coefficient according to Street type (βst).	1 Segregated bike lane	0,866
	2 Segregated bike lane on the sidewalk	0,894
	3 Non-segregated bike lane	0,922
	4 No bike lane	1
	Tree density level	**βtd**
Estimation of coefficient according to Tree density (βtd)	1 Yes- High	0,9
	2 Yes-Medium	0,95
	3 Yes-Low	0,95
	4 No	1
	Average daily traffic (vehicles/day)	**βADT**
Estimation of coefficient βADT according to the average daily traffic (ADT).	< 10.000	1
	10.000-20.000	1,182
	20.000-30.000	1,204
	30.000-40.000	1,23
	40.000-50.000	1,265
	50.000-60.000	1,311
	60.000-70.000	1,374
	70.000-80.000	1,465
	80.000-90.000	1,603
	> 90.000	1,828

Source: (Romanillos, 2012)

We conducted our study using previous findings on cycling speed for Madrid. We think it is positive to contribute to a heuristic-based approach that uses previous knowledge (without being redundant) and continues a line of research. However, our results may be impacted by this previous data, and this should be carefully considered when analyzing the results.

4.2 Visualizing micromobility flow through the journey planner

The second part of the study concerns testing the journey planner by using trip data from different micromobility operators. To this end, the authors established data-sharing collaboration agreements with two of Madrid's most important private micromobility operators. In the case of BiciMAD, this was unnecessary because they have an open data website. The timeframe covered for all the trip datasets was the entire 2019 year.

- BiciMAD: data was extracted from the website: https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-(1). They monthly upload the datasets (in JSON format) containing information from movements (trips) and stations. BiciMAD datasets offer the location (xy coordinates) of the trip origin and destination as well as the exact time when the trip started (timestamp).

- Movo: the company provided us with a dataset (in JSON format). Movo datasets offer information on trip origin and destination coordinates, trip origin and destination timestamp and the vehicle type (if it is a moped or scooter).
- Muving: the company provided us with a dataset (in CSV format). Muving datasets offer information on trip origin and destination coordinates, trip origin and destination timestamp, trip time (minutes) and trip distance (km).

Once we obtained the trip data, we processed it in Python and cleaned the datasets, eliminating erratic data and those trips that did not last between a minute and two hours as was recommended in (Arias-Molinares et al., 2023). The following step was to create the routes with the Network Analyst tools of ArcGIS Pro, uniting origins and destinations by using the journey planner (shortest path for mopeds and friendly route for bikes and scooters) (see Figure 2). Next, we proceeded to summarize (count) the routes that passed through each street link to obtain the micromobility flow. Finally, with the resulting flows, we elaborated a series of maps showing its distribution throughout the city for both weekdays and weekends and by each mode (bike, moped and scooter). We also elaborated a map summarizing all micromobility flow for all the modes (bikes + mopeds + scooters). These maps helped to visualize the most important paths for these services and how the vehicle flow is distributed across different scenarios (weekdays/weekends).

Figure 2. Example of the two types of routes calculated by the journey planner (yellow: shortest path, pink: friendly route); Source: own elaboration

5 Results and discussion

We have tested the proposed cyclist journey planner estimating the routes made during the entire 2019 (proxy of routes connecting origin with destination points). The delivered “shortest” (for moped) and “friendly” routes (for bikes and scooters) show that the journey planner works, although it is still in a beta version (under development). However, findings related to Madrid’s dynamic show to be consistent with spatio-temporal travel patterns found in previous studies (Arias Molinares et al., 2023 Romanillos, 2018; Talavera-García & Pérez-Campaña, 2021).

Based on the data samples used for this study, our results show that bikes were the most used mode in Madrid during 2019, on both, weekdays and weekends. During weekdays, there were almost 2.7 million trips, followed by mopeds (almost 500 thousand trips) and, lastly, scooters (almost 60 thousand trips) (see Table 6). Interestingly, the ratio of bike trips and the other two shared modes is reduced during weekends. On weekdays, we observe that for each moped trip there was about six bike trips, and for each scooter trip, there were about 46 bike trips. However, on weekends, for each moped trip there were 3 bike trips (36 in the case of scooters). This reduction of the ratio of bike/moped-scooter trips means that during weekends, people tend to use the different modes more homogeneously, while on weekdays bikes are the mode that concentrate an intense usage, possibly for commuting reasons as supported by (Arias-Molinares et al., 2023).

Table 6. Descriptive results

Scenario	Characteristics	Bike	Moped	Scooter
Weekdays	Total routes (entire 2019)	2.678.734	441.051	58.361
	Av daily routes	7.339	1.208	160
	Mean trip distance (km)	2,45	3,07	2,52
	Mean trip travel time (min)	13,61	18,23	13,93
Weekends	Total routes (entire 2019)	707.163	242.243	19.329
	Av daily routes	1.937	664	53
	Mean trip distance	2,37	3,14	2,57
	Mean trip travel time	13,26	18,65	14,20

Source: own elaboration

In the case of travel times and distances, for the case of bikes we observe that both indicators are lower during weekends meaning that its usage corresponds to shorter routes. On the contrary, during weekends people tend to travel longer distances (and hence higher travel time) when using mopeds and scooters. This use of other shared modes (mopeds and scooters) for longer distances supports what many experts point to when stating that these modes are preferred for leisure/recreation activities during weekends (Arias-Molinares et al., 2021; Bai & Jiao, 2020; Jiao & Bai, 2020).

The maps in Figure 3 show the micromobility routes (2019) by mode (bike, moped and scooter) and scenario (weekday and weekend). As we applied the same scales for weekday and weekends to make the maps comparable, we decided to leave the line widths in the same value. This was necessary because of the big differences between the scenarios (weekdays have more trips than weekends).

The map illustrates the descriptive results as bikes show a higher average daily flow in the city reaching more than 500 trips per day in some streets, compared to the almost 60 and 7 trips made in mopeds and scooters respectively. Moreover, we observe that the differences during weekday and weekends are more notorious in the case of bikes and scooters, while mopes show an intense usage during weekdays but also during weekends. The maps clearly show the most important axes of the city in terms of micromobility flow; for example, the north-south axe of La Castellana Street, which supports the recently started construction of the first continued north-south cycling segregated infrastructure in this area (Ayuntamiento de Madrid, 2019).

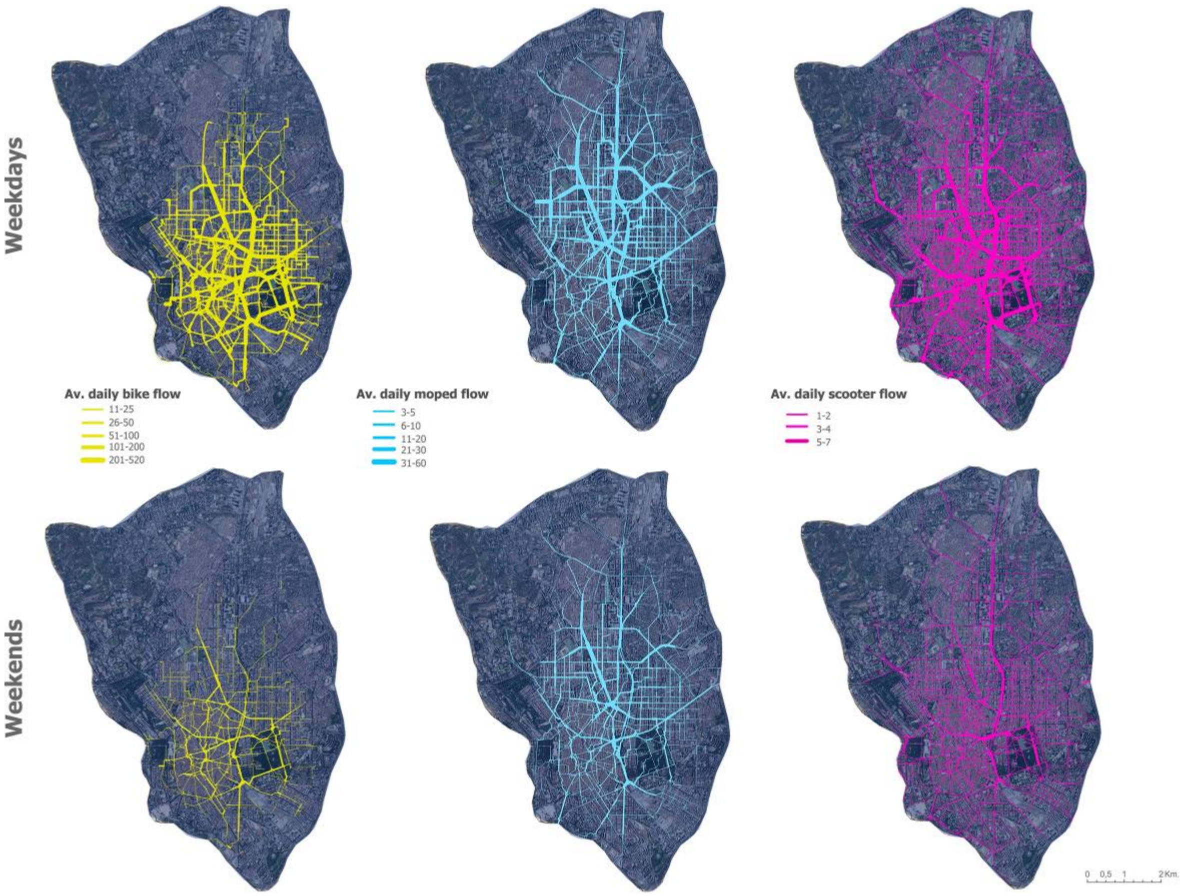


Figure 3. Micromobility routes (2019) by mode (bike, moped and scooter) and scenario (weekday and weekend); Source: own elaboration

When visualizing all modes together (bikes + mopeds + scooters) (see Figure 4), the areas with the most vitality in terms of micromobility flow are revealed. During weekdays, we see the relevance of the north-south axes like Castellana and Bravo Murillo Street as well as some east-west axes around the city centre. However, during weekends, Castellana Street, which is known for concentrating working sites, shows a considerably lower flow as most people are not working in those areas. On weekends, the flow is concentrated around recreational spots/touristic sites, while on weekdays micromobility flow is more homogeneously distributed around the city.

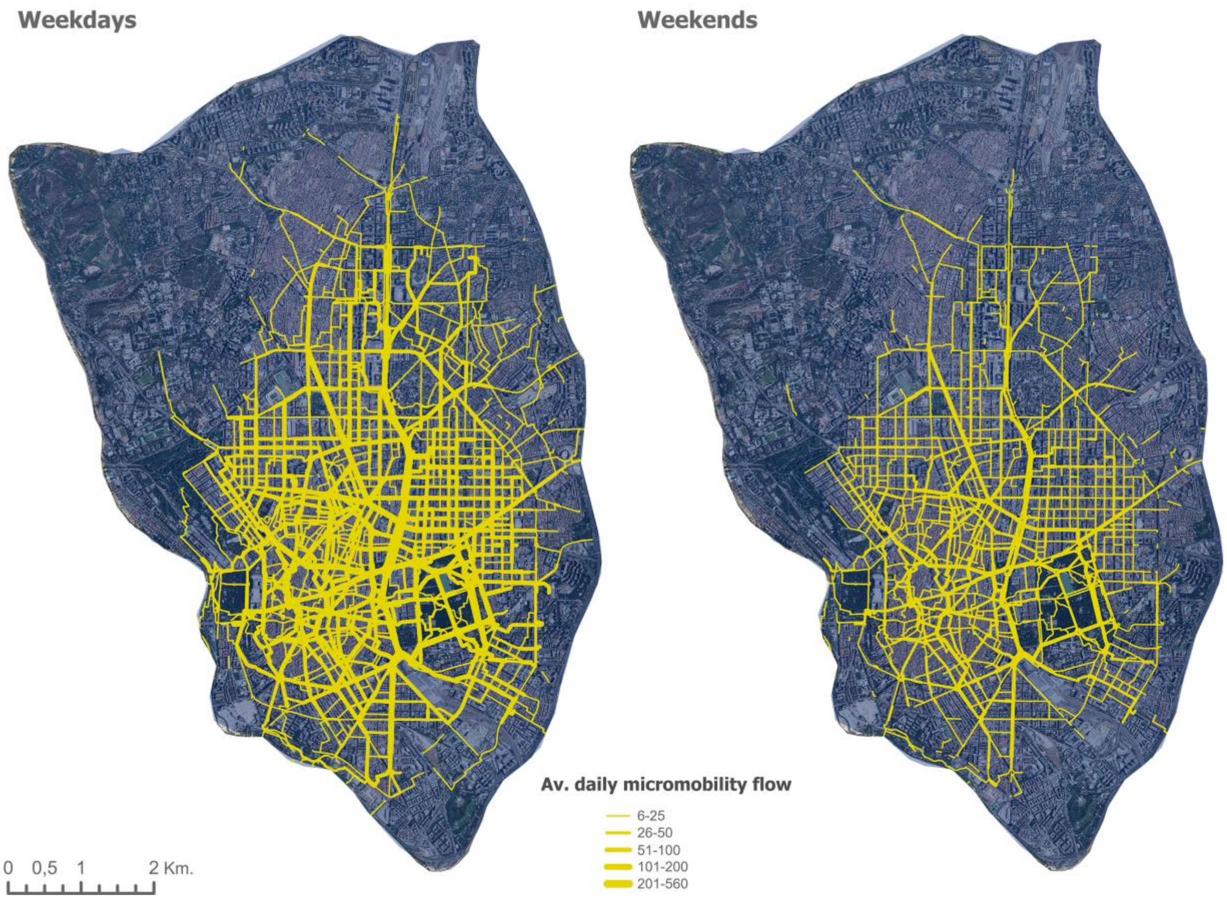


Figure 4. Average daily micromobility (bike + moped + scooter) flow in Madrid (2019) by scenario (weekday and weekend); Source: own elaboration

6 Conclusion

In this study we have collected and processed relevant information (built environment and travel patterns) for micromobility users in Madrid to create a *beta* version of a micromobility journey planner. Meaning that this work could and should be improved in the near future to include more variables, develop new and better assumptions that give the best results possible. But for now (as no other study on this topic was found for Madrid), we think our estimations are a start point.

We have tested this journey planner using Madrid’s trip data for bike, moped and scooter trips during 2019. Our study contributes to the revised literature by comparing different shared modes simultaneously, as many of the revised papers just focused on one (bikes, mopeds or scooters). This was done using the Dijkstra’s algorithm for the “shortest route” according to time (in the case of mopeds) and a “friendly route” (for bikes and scooters) that considers other variables, such as cycling infrastructure, green areas or slope. The variables used for creating the friendly route have been shown to be relevant for cyclists when deciding their routes, as supported by (Romanillos, 2018). After obtaining the estimated routes, we have finally elaborated maps that illustrate the estimated flows that correspond to micromobility services.

Our study did not measure the fit between estimated routes and real ones, therefore they should be considered as a proxy of what could be really happening with mobility patterns. However, as an exercise to approximate micromobility flows, our estimated tracks could give us a clear idea of how it functions. Based on the flows derived and plotted in the resulting maps, we find that our results are consistent with previous findings, as micromobility users concentrate on the city center during weekends and travel by the main streets during weekdays. High micromobility flows are observed mainly around working sites and where cycling infrastructure is available during weekdays and in the city center and green areas during weekends. These resulting maps are relevant at two different levels: firstly, they help to visualize the paths that micromobility users may follow. Secondly, at an urban scale, they allow transport and mobility planners to analyze how micromobility flow could be distributed across the urban network which is vital to understand the most important axes in terms of public policy. Visualizing how Madrilenians move with shared bicycles, mopeds and scooters simultaneously is relevant to plan for new infrastructure that promotes micromobility usage. Apart from considering different modes, we also consider different dynamics according to the day of the week (weekdays and weekends). This information is vital for planners to implement policies and interventions where they are mostly needed, according to the existing demand, which is made more visible through our analyzes and maps. In addition, journey planner apps can help to visualize how vehicle flows concentrate in certain streets, something that promotes the creation of a positive feedback loop: a higher concentration of vehicles (more cyclist density, for instance), makes the group and the mobility along these streets more visible, increasing the safety of the streets, that therefore become more attractive, attracting even more flow. As a limitation of our approach, we could highlight that some of the selected variables may have different values at different days' hours (e.g., daily traffic), making dynamic variables seen as static ones. This is something to improve in future studies with more available data. Other further research could test the journey planner with the real tracks. This was a limitation in our study as the track (route) information was not available (we have only the origin and destination point of each trip). Other future lines of research could analyze the profile of cyclists and micromobility users in general to understand their sociodemographic characteristics and travel patterns.

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Declaration of interest statement

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

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