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The pulse of the cycling city: visualising Madrid bike share system GPS routes and cycling flow

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ABSTRACT

With the aim of shifting towards a more sustainable urban transport model, cycling mobility is being promoted in many cities and, in consequence, Bike Share Systems have been the focus of attention in an increasing number of studies over the past years. However, we know very little about the impact of these BSS in cities beyond the station level. What paths do cyclists follow? What are the most important urban arteries in terms of cycling flow? These are important questions to be addressed in order to implement policies and infrastructure where they are really needed. The main goal of this study is to visualise the cycling flow derived from Madrid BSS activity, obtained by processing over 250,000 GPS routes, and to provide an analysis of how this flow is distributed across the urban street network at different moments. We explore the diverse levels of use over the course of the day, and during the weekdays, weekends or holidays, as well as the different cycling patterns of frequent and occasional users.

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1. Introduction

With the aim of shifting towards a more sustainable urban transport model, cycling mobility is being promoted in many cities. This is done essentially by implementing different types of policies, by building cycling infrastructures and by fostering the implementation of Bike Share Systems (BSS). Although these bike share programmes have existed for over 50 years, they have gained popularity and have grown exponentially over the past 10 years, in general, worldwide (Fishman, Washington, & Haworth, 2013), and particularly, in Spain (Anaya & Castro, 2011). In consequence, recently published research on BSS has been extensive, with different focuses. Some studies have visualised BSS activity, identifying trends usually based on the analysis of the docking stations' performance, observing the number of trips starting and ending at the station level (Borgnat et al., 2013; O'Brien, Cheshire, & Batty, 2014; Zaltz Austwick, O'Brien, Strano, Viana, & Gomez-Gardenes, 2013). Of great significance is the number of studies that analysed BSS imbalances produced by the different levels of attraction and generation of trips at the station level (Goodman & Cheshire, 2014), often with the aim of developing efficient bike redistribution strategies (Lin & Chou, 2012; Raviv, Tzur, & Forma, 2013). With the similar aim of implementing more balanced BSS, other studies have modelled demand (Systems & Lackner, 2013) or have developed

models that optimise the location of BSS stations (García-Palomares, Gutiérrez, & Latorre, 2012).

However, as far as we know, the study of how BSS are impacting cities beyond the station level had yet to be addressed. While a significant number of studies have recently focused on the GPS analysis of casual cyclists' routes (Romanillos, Zaltz Austwick, Ettema, & De Kruijf, 2016), based on tracks collected by apps such as Strava (Jestico, Nelson, & Winters, 2016), or based on the routes collected by research initiatives (Romanillos & Zaltz Austwick, 2015), only a couple of studies have focused on the exploration of real BSS routes. First, the route choice analysis performed by Khatri (2015), based on approximately 12,000 trips collected through the Phoenix BSS bikes equipped with built-in GPS trackers, and recently, the research published by Wergin and Buehler (2018), analysing 3596 trips obtained by introducing GPS trackers into 94 bikes in the Washington DC BSS in 2015. Given the exponential growth of BSS in many cities across the world, the study of the real BSS users' routes must be addressed in further depth. How is the BSS cycling flow distributed across cities' street networks? What are the paths that the BSS users follow? What are the most important arteries of the city in terms of cycling flow? These are important questions to answer in order to understand the current use of BSS across the

city and, in consequence, in order to obtain the necessary understanding to promote efficient policies and infrastructure where they are really needed.

The goal of this study is to visualise the Madrid BSS (BiciMAD) cycling flow, obtained from processing over 250,000 GPS routes, and to provide an analysis of how this flow is distributed across the city street network at different moments (studying the different levels of use over the course of the day, or during the weekdays, weekends or holidays). It also explores the cycling patterns that correspond to different types of BSS users (frequent users vs. occasional users or potential tourists). The visualisation of these different levels of BiciMAD cycling flow is presented here through the [Main Map](#) and through a video visualisation that illustrates the BSS cycling flow over the course of a day.

2. Case study, data and methodology

2.1. Case study

This research focuses on the study of the cycling routes and flow derived from BiciMAD, the Madrid Bike Share System. BiciMAD was launched in June 2014, comprising 1560 bikes and 123 docking stations and, after a first expansion phase in 2015, the system is currently operating with 2028 bikes and 172 stations. A third expansion phase is meant to take place in 2018, adding 42 new stations and 468 bicycles to the system, – reaching 214 stations and 2496 bicycles, and the current plan is to comprise over 4000 bicycles and 350 bike stations by 2019 ([Lantiga, 2017](#)). BiciMAD currently covers the inner-central area of Madrid, with nearly 850,000 inhabitants, and with approximately 8.9 million tourists in 2016 ([Munkácsy & Monzón, 2017](#)).

BiciMAD comprises almost all the characteristics and features of a fourth-generation scheme, such as bicycle redistribution innovations (automated technologies, incentivising user-based redistribution, etc.), travel card integrated with other transportation modes (public transport, car-sharing, etc.), electric power-assisted bicycles (with an electric pedal assistance up to 25 km per hour in the case of BiciMAD), bicycle tracking (GPS, RFID), state-of-the-art docking stations (solar power, touchscreen kiosks) and online apps offering information, such as real-time availability of bikes at stations ([Buehler & Pucher, 2012](#); [Midgley, 2011](#); [Munkácsy & Monzón, 2017](#); [Shaheen, Guzman, & Zhang, 2010](#)).

There are two types of BiciMAD users regarding subscription to the system: frequent users and occasional users. Frequent users pay an annual membership (25€ in 2018), and then obtain lower rental prices than occasional users, who can obtain a free card for 1, 3 or 5 days, and only pay for the trips completed during these days. A fact that could potentially affect the BiciMAD travel patterns analysed in this study is that, while

registered or frequent users of most bike-sharing systems do not pay for trips with a duration under 30 min, BiciMAD subscribers pay for any ride, including those under 30 min (€0.5). In principle, this measure was established in order to avoid short bike-sharing trips instead of walking, but it was also intended to partially refinance the expensive operation of implementing an electric power-assisted system.

2.2. Data

The study is based on the analysis of a collection of data provided by the Municipal Transport Company (EMT), which is currently managing BiciMAD. The data set corresponds to the 253,556 routes recorded by the BSS during April 2017, although we left aside the trips derived from BSS redistribution and focused on the analysis of the resulting 230,238 trips. For each trip, the data set provided information on both origin and destination stations and docks, the duration of the journey in seconds, the specific date and starting time (aggregated per hour, in order to protect the anonymity of users), age according to 6 ranges (0–16, 17–18, 19–26, 27–40, 41–65 and over 65), and the type of user (frequent user, occasional user, and unknown user, with 215,371, 4578 and 10,289 routes for each group, respectively). Based on the date field, we classified the routes according to four different typical days, considering that they could present different travel patterns. More specifically, we identified and categorised the trips that took place on the weekdays from Monday to Thursday, on Fridays, at the weekends and on holidays (considering Easter, from Thursday 13 to Sunday 16 April 2017).

The data set was basically a collection of GPS track points, recorded with an average interval of 75 s. This temporal resolution is much lower than the one typically obtained with commercial smartphone apps or GPS devices ([Romanillos & Zaltz Austwick, 2015](#)), which tends to be around 2 s. In consequence, the real map-matched route lines had to be estimated as the shortest path between the track points, as we will explain later. The track lines were map-matched to a detailed street network, based on the March 2013 version of *TomTom*® for the Spanish road network, which is currently the most accurate street network we have found in Madrid. It consists of over 160,000 street segments for the metropolitan area of Madrid that covers the collected BSS cycling routes, and includes not only roads, but also pedestrian streets and basic bike infrastructure. For greater accuracy, we edited the network and updated the bike infrastructure, including all the eight different kinds of bike infrastructures included in the Madrid Cycling Master Plan.

Another important data set bears on the two main types of bike infrastructure in Madrid, according to the Madrid City Council classification: *Ciclocarriles* (on-road or non-segregated from traffic bike lanes)

and *Vías Ciclistas* (bike lanes somehow segregated from traffic, not necessarily with a physical barrier). The data, updated in 2017, was downloaded from the Madrid Data Council Open Data Platform (<http://datos.madrid.es>). A map representing this existing cycling infrastructure, along with BiciMAD bike stations, is provided in the annex.

In addition, the **Main Maps** include the most updated orthophoto (2016) from the Spanish Geographic Institute Aerial Photographic Plan (PNOA), as a faded background base map.

2.3. Methodology

First, the JSON track points were imported as GeoJSON files into a GIS environment using Python programming language and the free and open software Mongo DB. Then, we exported the GeoJSON track points as Geodatabase point feature classes using the free and open software QGIS, and subsequently generated the GPS track lines by joining the track points. We eventually map-matched the GPS track lines to the detailed street network previously described, obtaining what we call the map-matched route lines, by estimating the shortest path between the track points, according to Dijkstra's algorithm, using the *New route* ArcGIS's Network Analyst tool (vs. ArcMap 10.4).

Then, these estimated real routes, or map-matched route lines, allowed us to calculate the real trip distance and, by considering the duration of the journey, to calculate the average trip speed. Since we had information on the type of user and the date and time of every journey, we decided to analyse the average trip distance, duration and speed according to different periods of time and types of users. The general results are shown in **Table 1**, **Figure 4** illustrates the number of trips according to distance and user type, and we discuss the results in the next section.

Our main goal was to generate diverse maps showing the cycling flow derived from BiciMAD, assigned to

the street network. In order to do so, we split the map-matched routes according to the street network junctions, and we then summarised the number of trips at the street segment level, for the two different scenarios, illustrated on the **Main Map**. The first scenario corresponds to the average cycling flow on a weekday, and the second scenario to the average cycling flow on a weekend day. In order to better understand the cycling flow dynamics, we also decided to calculate and represent the activity at the BSS station level, adding up the number of departures and arrivals at each station, so we can easily relate the most important streets in terms of cycling flow to the most significant stations in terms of attraction and generation of trips, for the two scenarios considered. **Figure 1** illustrates the BSS cycling footprint by representing the original GPS track lines, as well as by visualising the street network assigned flow derived from the map-matched route lines.

In addition to the maps that illustrate the different BSS dynamics during weekdays and weekends, we analysed the use of the BSS over the course of a day, based a graph that illustrates the percentage of trips per hour (**Figure 5**), and based on some statistics regarding cyclists' average speed and trip distances, according to the following 7-time intervals (7–10 h, 10–13 h, 13–16 h, 16–19 h, 19–22 h, 22–1 h and 1–7 h). We defined these time intervals in order to distinguish the different travel patterns that corresponds to the diverse peaks of activity identified in **Figure 5**.

This analysis of BiciMAD activity over the course of a day was performed for each of the four different typical days defined previously (Section 2.2), in order to identify potential differences. **Figure 4** illustrates the aggregated number of trips for each type of day and time interval. Finally, the video visualisation illustrates BiciMAD routes over the course of a day by merging all the routes from a single week (from the 17th to the 23rd of April), making the difference between the weekday and the weekend routes.

Table 1. Basic route statistics according to different periods of time and type of users.

Target routes	Av. speed (kph)	Av. distance (m)	Av. time (s)	Av. time (min)	Count
Total routes	14.06	3104	1028	17.13	226,253
Type user 1 (frequent user)	14.29	3011	954	15.90	212,012
Type user 2 (occasional user)	8.59	5518	2910	48.49	4279
Weekday routes	14.35	2993	948	15.79	158,246
Weekend routes	13.44	3256	1161	19.34	49,700
Eastern routes	13.24	3652	1363	22.71	18,307
Weekday frequent users	14.51	2935	898	14.96	150,246
Easter occasional users	8.81	5940	2943	49.05	1773
Weekends occasional users	8.55	5641	2998	49.97	1056
Weekends frequent users	13.76	3120	1054	17.57	45,232
Basic route statistics of frequent users during weekdays over the course of the day					
7–10 h	15.71	2962	829	13.82	28,002
10–13 h	13.20	3280	1206	20.09	25,354
13–16 h	13.78	3167	1075	17.92	41,246
16–19 h	13.70	3305	1134	18.89	46,341
19–22 h	13.50	3049	1026	17.10	47,694
22–01 h	14.62	2833	874	14.56	27,124
01–07 h	15.53	2874	884	14.74	10,492

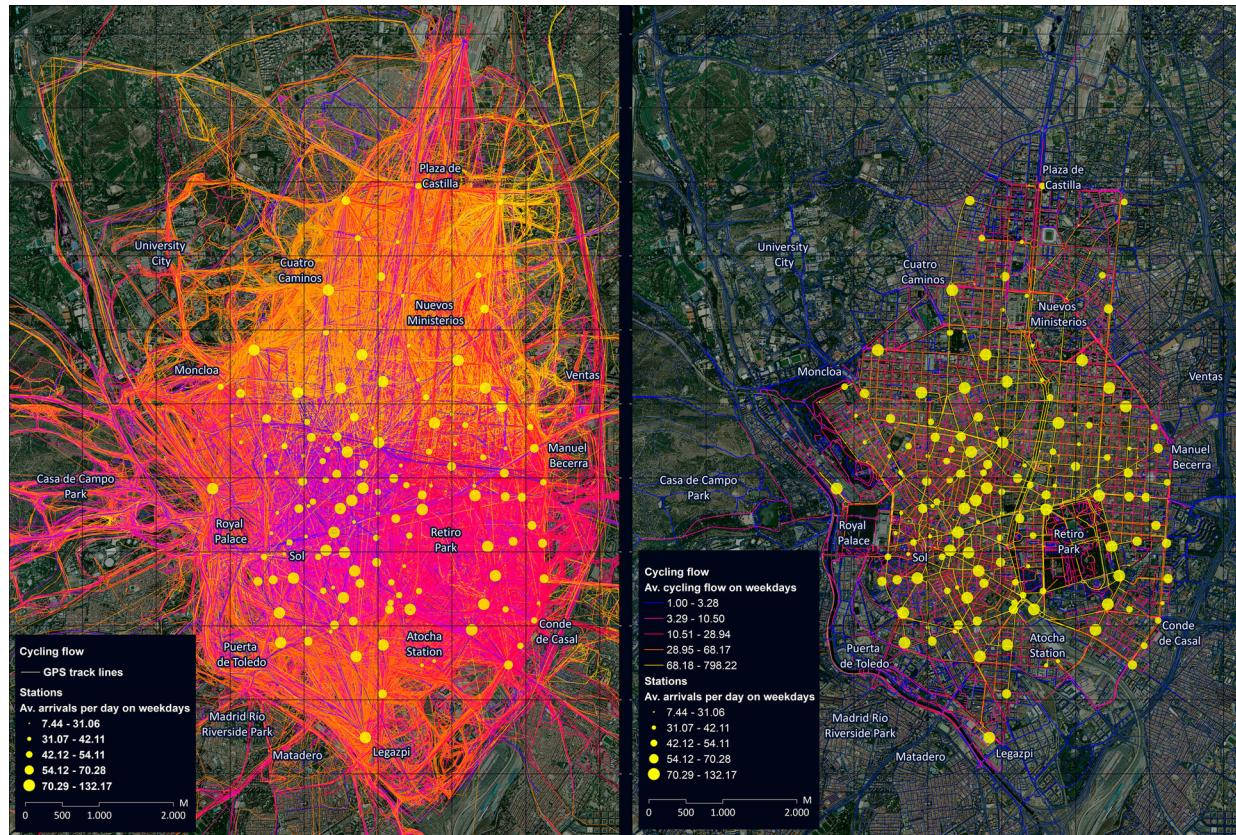


Figure 1. GPS track lines (left) and assigned cycling flow considering map-matched routes (right).

3. Results

3.1. Results on BiciMAD cyclists' travel patterns

The results obtained clearly illustrate the different dynamics of use that BiciMAD experiences over time and according to its different types of users. First, the analysis of average trip distances, durations and speeds, reveals significant differences, as is shown in Table 1. The most remarkable observation are the radically different figures shown by frequent and occasional users. While the average frequent users' cycling speed is 14.29 kph occasional users' is only 8.59 kph. Although frequent users have more experience and, in consequence, may be more confident and able to circulate at a higher speed, considering that most of these occasional users are tourists, the most probable reason for such a dramatic difference is the fact that tourists tend to stop at different points and take their time to observe and enjoy the city. The average speed is for a tour visit, which is the main purpose of the journey, not just travelling from one location to another. The difference shown in terms of trip distance is most likely due to the same reason: the average distance travelled by frequent users is 3.01 km, while occasional users' average distances almost double this distance, rising up to 5.52 km. When it comes to the average time, the average trip duration is three times that of occasional users, with 15.9 and 48.5 min, respectively. Occasional users' figures are quite different from frequent users, not only during weekdays, but also with

regard to weekends and holidays, when the purpose of the journey will most likely be related to leisure activities, not commuting. During weekends and holidays, frequent users' trips are slightly longer than during the weekdays, and the average speed is somewhat lower than during the weekdays (3256 m vs. 2933 m and 13.44 kph vs. 14.35 kph, respectively).

Another remarkable difference is found when analysing frequent users' figures over the course of the day. The average speed of frequent users' trips during the morning peak hour is the highest, at 15.71 kph, which can be associated to the rush typical of commuting trips. The average speeds during the rest of the day are clearly lower, around 13.50 kph, before they once again rise after 10pm, and especially after 1am. Our hypothesis regarding this fact, is that this increased speed at night could be explained by the quasi-absence of motor traffic, which means that cyclists most likely do not stop at every junction or traffic light, significantly reducing travel time.

A deeper understanding of cyclists' travel distances is provided by Figure 2, which illustrates the percentage of routes according to distance intervals in a different line graph for trips during weekdays, weekends and holidays (Easter), and also for frequent and occasional users. Although the average distances are different (especially between frequent vs. occasional users), we observe a similar pattern for all of them, with the highest percentage of trips always close to a 2-km. distance.

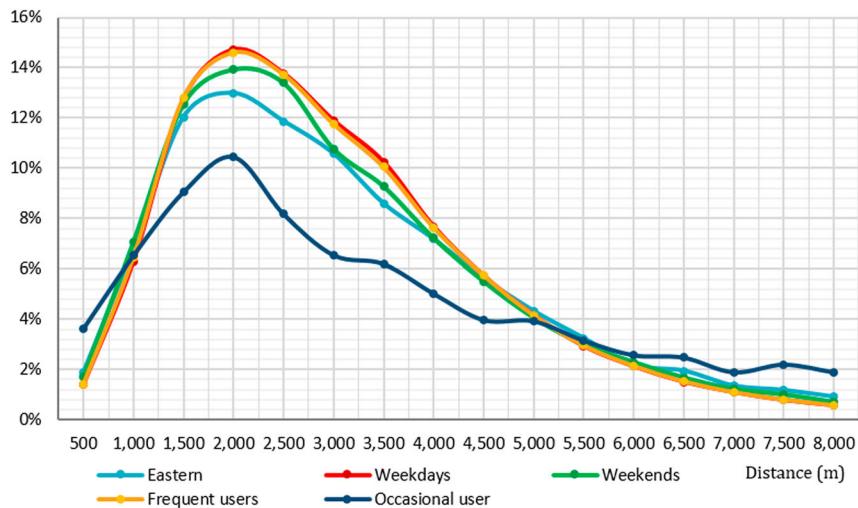


Figure 2. Percentage of trips according to distance.

The analysis of BicIMAD routes according to average time revealed that 92.6% of frequent users' trips are under 30-min length, so the €0.5 fee for trips under this duration is applicable to the vast majority of the trips. Considering frequent users' average speed, a 30-min trip is 5436 m in distance. Figure 2 also clearly illustrates the low percentage of trips above this distance.

The analysis of BiciMAD users' travel patterns according to age reveals some interesting findings. Figure 3 represents the percentage of users according to 5 age ranges (0–18, 19–26, 27–40, 41–65 and over 65), after merging the first two age range groups originally provided (0–16 and 17–18), and considering both frequent and occasional user groups (based on a sample of 212,012 and 4279 users, respectively). Figure 3 reveals an important concentration of users between 27 and 40 years old, especially when comparing the percentages with Madrid's total population (Madrid City Council, 2017). Users between 27 and 40 years old are approximately 50% of users, in the case of frequent users, and significantly more in the case of occasional users, at almost 65%. Occasional users do not necessarily provide age information through their

registration process, and in this case, our original sample is reduced to just 73 users, corresponding to a 9.5% statistical sampling error with a statistical confidence level of 90%. This low sample may explain the complete absence of occasional users in the first and the last age range groups. In any case, their representation is certainly low in the case of frequent users, with just 0.80% and 0.73% for the (0–18) and the (>65) age groups respectively.

Analysis of average cyclist speed and trip distance according to age reveals certain patterns. As Figure 4 illustrates, in the case of Frequent users, average cycling speeds and average trip distances remain quite stable, with slightly higher speeds and shorter trips in the age group between 27 and 40 years old. Age seems to affect more occasional users in both speed and distance, with a drop in values as the age is increased. The absence of occasional users in the first and the last age range groups makes these graphs incomplete.

Figure 5 illustrates the evolution of BiciMAD activity over the course of a day, representing the percentage of trips per hour, and distinguishing between the trips that took place on the weekdays from Monday through Thursday, on Fridays, on the weekends and on

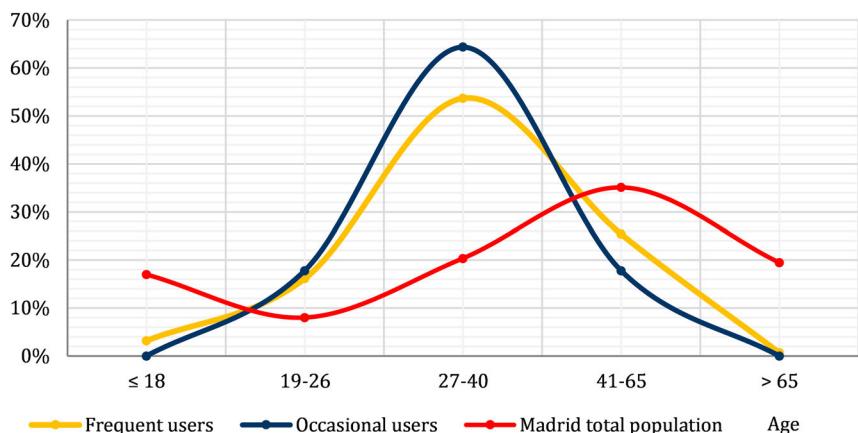


Figure 3. Percentage of BiciMAD users according to age.

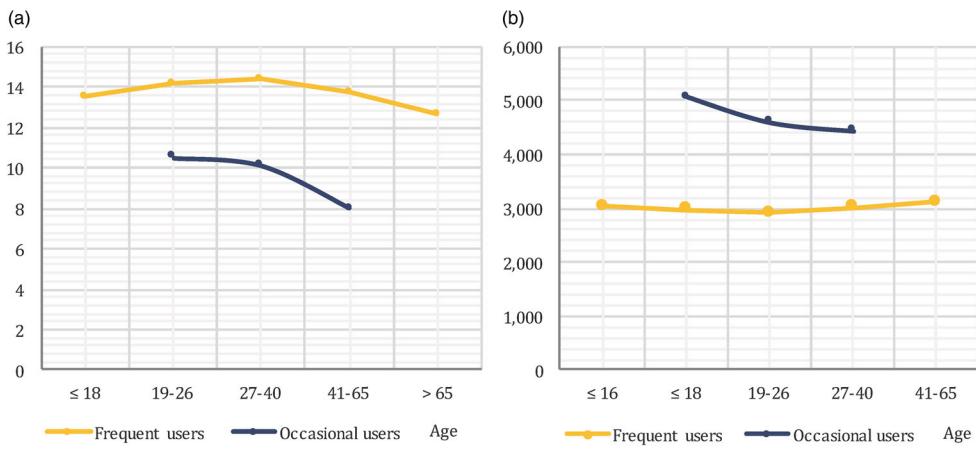


Figure 4. Average BiciMAD cyclists' speed (kph) (a) and trip distance (m) (b).

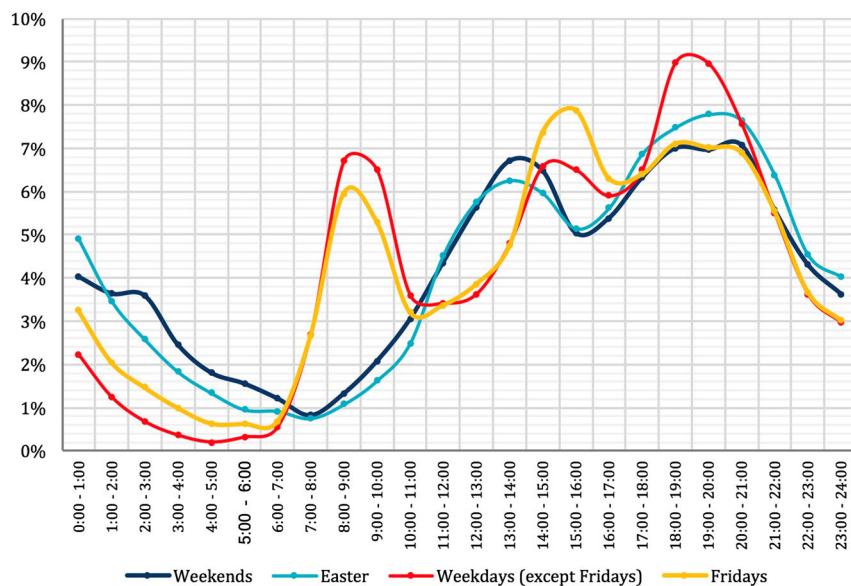


Figure 5. Percentage of trips per hour over the course of a day.

holidays (considering the dates previously defined). The figure shows a very different pattern when comparing weekday activity vs. weekend and holiday activity. Weekdays shows a clear morning peak hour that corresponds to commuting trips, and then a second peak in the afternoon and evening, which is earlier in the afternoon on Fridays. This is due to the fact that it is common to finish working early on Fridays in many companies or sectors. The morning peak will most likely also be associated with the use of BSS for first and last-mile public transit connections, explaining the important activity of some stations close to transport hubs (such as Atocha or Moncloa), illustrated by the [Main Map](#). Weekends and Easter days' activity perform in a similar way, with a reduced activity early in the morning and a continuous increase towards the afternoon and the evening. In these cases, the night activity after 1am is also remarkable, showing an important use of BiciMAD associated with nightlife during weekends and holidays, which is characteristic of the city of Madrid.

3.2. Results on BiciMAD cycling flow distribution across the urban network

Although the [Main Map](#) visualises distribution of the cycling flow from BiciMAD activity across the street network, as we explain in the next section, we considered it necessary to analyse this distribution in further detail. With the aim of understanding the extent to which cycling flow is more or less distributed across the urban street network, we calculated the percentage of street network segments that supported different amounts of cycling flow, as [Figure 6](#) illustrates.

This figure reveals, for instance, that all the street segments with an average cycling flow per day over 10 (in other words, the streets with an average of over 10 BiciMAD users who ride along them per day), is concentrated in 30% of the urban street network, while only approximately 5% of the street network segments have an average cycling flow over 100. This graph reveals how concentrated cycling flow is in Madrid, but we find the possibility of comparing this graph to the graph of other case studies

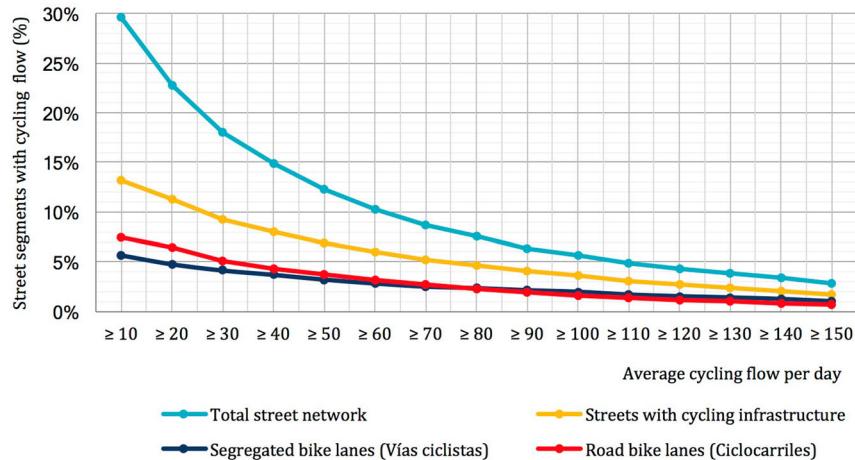


Figure 6. Street network segments with cycling flow (%).

interesting, since cities with high cycling flow concentrated in a few streets could be easily distinguished from the cities where cycling flow is more distributed. It is important to highlight that, when analysing this distribution of cycling flow, we are only considering the street network within the M30 peripheral street of Madrid, which is the boundary of the area currently covered by BiciMAD. This area is illustrated in Figure A1, which at the same time represents the existing cycling infrastructure (Figure 7).

In addition, with the aim of discovering the amount of cycling flow captured by the existing network of cycling infrastructure, we have repeated these calculations, considering the streets with segregated bike lanes (*Vías ciclistas*) and the ones where road bike lanes – non-segregated from traffic – (*Ciclocarriles*) have been implemented. Figure 6 illustrates, for instance, that approximately 14% of the streets with

an average cycling flow per day over 10, is concentrated in streets with any kind of cycling infrastructure, and that the percentage of network segments that correspond to streets with road bike lanes or segregated bike lanes is approximately 8% and 6%, respectively. These results provide highly valuable information for planning new bike lanes in Madrid.

4. The Map

The Main Map illustrates the cycling flow derived from the activity of Madrid BSS, assigned to the street network, after the process of map-matching thousands of GPS tracks collected by the system. The canvas includes two maps that illustrate the cycling flow in two different scenarios with a different focus.

The map on the left visualises the average cycling flow on a working day. The street segments are



Figure 7. Video visualisation clip.

represented according to the average cycling flow, assigned by summarising the number of total trips while overlapping each street segment over the month's working days and divided by the amount of working days in April (18). Regarding symbology, the flow ranges correspond to a quantile distribution. The map provides us with an overall view of the cycling footprint and its extension across the city network, and allows us to identify the most important arteries in terms of cycling flow, such as the two most important north-south axes (Bravo Murillo street and the Paseo de la Castellana Avenue), and other important east-west axes (Calle Mayor or Alberto Aguilera). Representation of activity at the BSS station level, by adding up the number of departures and arrivals at each station, provides a better understanding of BSS flow, since the most important cycling streets clearly connect the most relevant stations. The departures and arrivals are represented according to proportional circles, whose ranges and sizes also fall under a quantile distribution. The yellow-filled circles represent the average number of arrivals per day and the white circles the average number of departures per day. The overlapping circles provide information about the balance or imbalance of the stations in terms of attraction and generation of trips.

The map on the right focuses on the cycling flow on a weekend day, by representing, for each street segment, the difference between the average cycling flow on a weekend day and the cycling flow on a weekday, rather than by solely representing the cycling flow on weekends. By doing so, the difference between both scenarios becomes much clearer. In this case, yellow lines represent positive values; in other words, street segments where there is a greater cycling flow over the weekends than on weekdays. The rest of the colours represent negative values (streets with less activity during weekends) with ranges defined according to a quantile distribution. The overall footprint reveals significant differences, such as the increase in cycling flow in the most important parks of the city, including Madrid Río, the riverside park, the Casa de Campo, and some areas of El Retiro. However, this latter park also shows important activity on weekdays, since it is a more central and urban park. Other areas show a radical decrease in activity (the ones in dark blue), such as the Paseo de la Castellana and Bravo Murillo north-south axes, among the most important during weekdays. The activity shown at the station level also presents remarkable differences, with a strong concentration of activity in the stations around the city centre, and less activity around the Paseo de la Castellana, which is more connected to the financial and business centres of the city.

Both maps are quite complementary and illustrate the different uses of the city street network over time well, in terms of cycling flow, and this may constitute a valuable tool when defining the increasingly common different cycling policies and measures that many cities

are adopting temporally for weekdays and weekends. Although it may seem obvious, it is important to highlight that both footprints are somehow determined by the extension of the area covered by the BSS stations. The absence of bike stations in the University City or in the Casa de Campo Park, for instance, explains the low cycling flow values obtained in these two areas.

5. Dynamic visualisations

The visualisation was produced using the *Processing* programming language (<http://processing.org>), using code written for this purpose (<https://github.com/martin austwick/GPS-from-MySQL/tree/GPS-from-geojson>). The journeys were exported as geojson files, and a processing sketch was converted from geojson to .csv, which is more quickly read by Java/Processing (resulting in a 10 s for csv vs. a 120 s import time for geojson, for files of similar size, on a 2017 *MacBook Pro*). The 63,000 journeys were imported into memory in *Processing*.

Processing calculates the total length of the route and uses the durational information to create an average speed, and waypoints – locations where a bike is at a specific time point. An internal clock updates, and the code displays all data points the bike has visited since the last frame. In between frames, a partially transparent version of the underlying map is redrawn, meaning that the location of points in previous timestamps remains partially visible, creating the illusion of a continuous path. By decreasing transparency (increasing alpha value), those previous values become more strongly obscured, emphasising the 'current' position of cyclists; by increasing transparency (reducing alpha), prior paths are more obvious, at the expense of the most current data. With each frame, a jpg image is captured, creating some 6480 images (8 h at 6 images per minute) which, when assembled at 30 frames/s, results in a movie of under 4 min.

6. Conclusions

Estimation and visualisation of the cycling flow derived from Bike Share Systems across the street networks is crucial in order to have an overall understanding of the current use of BSS across the city, beyond the station level, and, in consequence, in order to promote efficient policies and infrastructure for the improvement of cycling mobility. This research answers the questions raised in the introduction section: how is BSS cycling flow distributed across the street network of cities? What are the paths that the BSS users follow? What are the most important arteries of the city in terms of cycling flow? Doing so in a visual way provides an important tool for policy makers, as well as for BSS managers.

This study also evidences the importance of analysing and representing the evolution of BSS dynamics over time. Illustrating different BSS activity on

weekdays and on weekends or holidays provides relevant information to consider when promoting policies or measures for specific periods of time, something that has become a trend in many cities. For instance, closing certain streets to motor traffic, in order to promote pedestrian or cycling mobility during weekends, Sundays, or specific holidays. In addition, analysing the use of the BSS over the course of the day and according to the different types of users provides important information in terms of the use of the system and the distribution of cycling flow during potential peak hours; for instance, this is crucial for the adoption of specific measures for these intervals of time at specific locations. At the same time, it identifies age profiles to be addressed as future target users of BiciMAD.

It is also clear that further analysis on the same data could enhance Madrid cycling network design and management. For example, the study almost directly yields most frequented O-D relationships non-covered with cycling infrastructure; or, it could be used to assess different options on specific itineraries, according to existing cyclist traffic levels

Future work should focus on continuing to monitor changes in cycling traffic flow as the BSS evolves, so we will be able to evaluate the impact of the system's growth (both in extension and in terms of increasing the BSS stations' density) as well as the impact of the implementation of new infrastructure or policies. In addition, it would be of interest to monitor the evolution of the amount of cycling flow supported by the cycling infrastructure, and compare it to the existing flow in other case studies.

Software

MongoDB and *Python* were used to process the original JSON data sets, both free and open-source software. *QGIS* (another free and open-source software) was used to export the obtained GeoJSON data sets to Geodatabase data sets. *ArcGIS 10.4* (payment software) was used to create the GPS route track lines and to produce the [Main Maps](#). *Adobe Illustrator CS6* (payment software) was used to ensemble the maps, texts and figures on the final canvas. The visualisation was produced using the *Processing* programming language (<http://processing.org>), using MySQL and associated java connectors (all of them free and open-source software or platforms). The video was edited with *Adobe Premiere CS6* (payment software).

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References

- Anaya, E., & Castro, A. (2011). Balance General de La Bicicleta Pública En España. In *3as jornadas de La Bicicleta Pública Santander*. Santander. Retrieved from https://s3.amazonaws.com/academia.edu.documents/31086906/1-EsterAnaya-AlbertoCastro.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1513012631&Signature=szVlhgSqFq4%2Fv5UhqNM7IgHXgjc%3D&response-content-disposition=inline%3Bfilename%3DBalance_General_de_Borgnat_P._et._al._2013.pdf

Borgnat, P., Robardet, C., Abry, P., Flandrin, P., Rouquier, J.-B., & Tremblay, N. (2013). A dynamical network view of Lyon 'S V ' Elo ' v shared bicycle system. *Dynamics on and of Complex Networks*, 2, 267–284.

Buehler, R., & Pucher, J. (2012). Walking and cycling in Western Europe and the United States: Trends, policies, and lessons. *TR News* (280).

Fishman, E., Washington, S., & Haworth, N. (2013). Bike share: A synthesis of the literature. *Transport Reviews*, 33(2), 148–165. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/01441647.2013.775612>

García-Palomares, J. C., Gutiérrez, J., & Latorre, M. (2012). Optimizing the location of stations in bike-sharing programs: A GIS approach. *Applied Geography*, 35(1–2), 235–246.

Goodman, A., & Cheshire, J. (2014). Inequalities in the London bicycle sharing system revisited: Impacts of extending the scheme to poorer areas but then doubling prices. *Journal of Transport Geography*. Retrieved from <http://linkinghub.eleverier.com/retrieve/pii/S0966692314000659>

Jestico, B., Nelson, T., & Winters, M. (2016). Mapping ridership using crowdsourced cycling data. *Journal of Transport Geography*, 52, 90–97.

Khatri, R. (2015). Modeling route choice of Utilitarian Bikeshare users from GPS Data. University of Tennessee. Retrieved from http://trace.tennessee.edu/cgi/viewcontent.cgi?article=4837&context=utk_gradthes

Lantiga, I. (2017). BiciMad Sobrepasará La M-30 Y Llegará Por Primera Vez a Ciudad Lineal Y Vallecas. El Mundo. Retrieved from <http://www.elmundo.es/madrid/2017/10/17/59e5b88e46163f204c8b4639.html>

Lin, J. H., & Chou, T. C. (2012). A geo-aware and VRP-based public bicycle redistribution system. *International Journal of Vehicular Technology*, 2012, 1–14.

Madrid City Council. (2017). Banco de Datos de Madrid. *Área de Información Estadística*. Retrieved December 15, 2017, from <http://www-2.munimadrid.es/CSE6/control/menuCSE>

Midgley, P. (2011). Bicycle-sharing schemes: Enhancing sustainable mobility in urban areas. *United Nations, Department of Economic and Social Affairs*, 8, 1–12.

Munkácsy, A., & Monzón, A. (2017). Impacts of smart configuration in pedelec-sharing: Evidence from a panel survey in Madrid. *Journal of Advanced Transportation*, 2017,

- 1–11. Retrieved from <https://www.hindawi.com/journals/jat/2017/4720627/>
- O'Brien, O., Cheshire, J., & Batty, M. (2014). Mining bicycle sharing data for generating insights into sustainable transport systems. *Journal of Transport Geography*, 34, 262–273. Retrieved from <http://linkinghub.elsevier.com/retrieve/pii/S0966692313001178>
- Raviv, T., Tzur, M., & Forma, I. A. (2013). Static repositioning in a bike-sharing system: Models and solution approaches. *EURO Journal on Transportation and Logistics*, 2(3), 187–229. Retrieved from <http://link.springer.com/10.1007/s13676-012-0017-6>
- Romanillos, G., & Zaltz Austwick, M. (2015). Madrid cycle track: Visualizing the cyclable city. *Journal of Maps*, 5(5), 1–9.
- Romanillos, G., Zaltz Austwick, M., Ettema, D., & De Kruijf, J. (2016). Big data and cycling. *Transport Reviews*, 36(1), 114–133.
- Shaheen, S., Guzman, S., & Zhang, H. (2010). Bikesharing in Europe, the Americas, and Asia. *Transportation Research Record: Journal of the Transportation Research Board*, 2143(1), 159–167. Retrieved from <http://trb.metapress.com/openurl.asp?genre=article&id=doi:10.3141/2143-20>
- Systems, D. T. & Lackner, B. (2013). Modeling demand for bicycle sharing systems – Neighboring stations as a source for demand and a reason for structural breaks. *TRB*, 1–19.
- Wergin, J., & Buehler, R. 2018. Where do bikeshare bikes actually Go? An analysis of capital bikeshare trips using GPS data. *Transportation Research Record*, (January), 2662, 12–21.
- Zaltz Austwick, M., O'Brien, O., Strano, E., Viana, M., & Gomez-Gardenes, J. (2013). The structure of spatial networks and communities in bicycle sharing systems. *PLoS ONE*, 8(9), e74685, 1–17.

Appendix

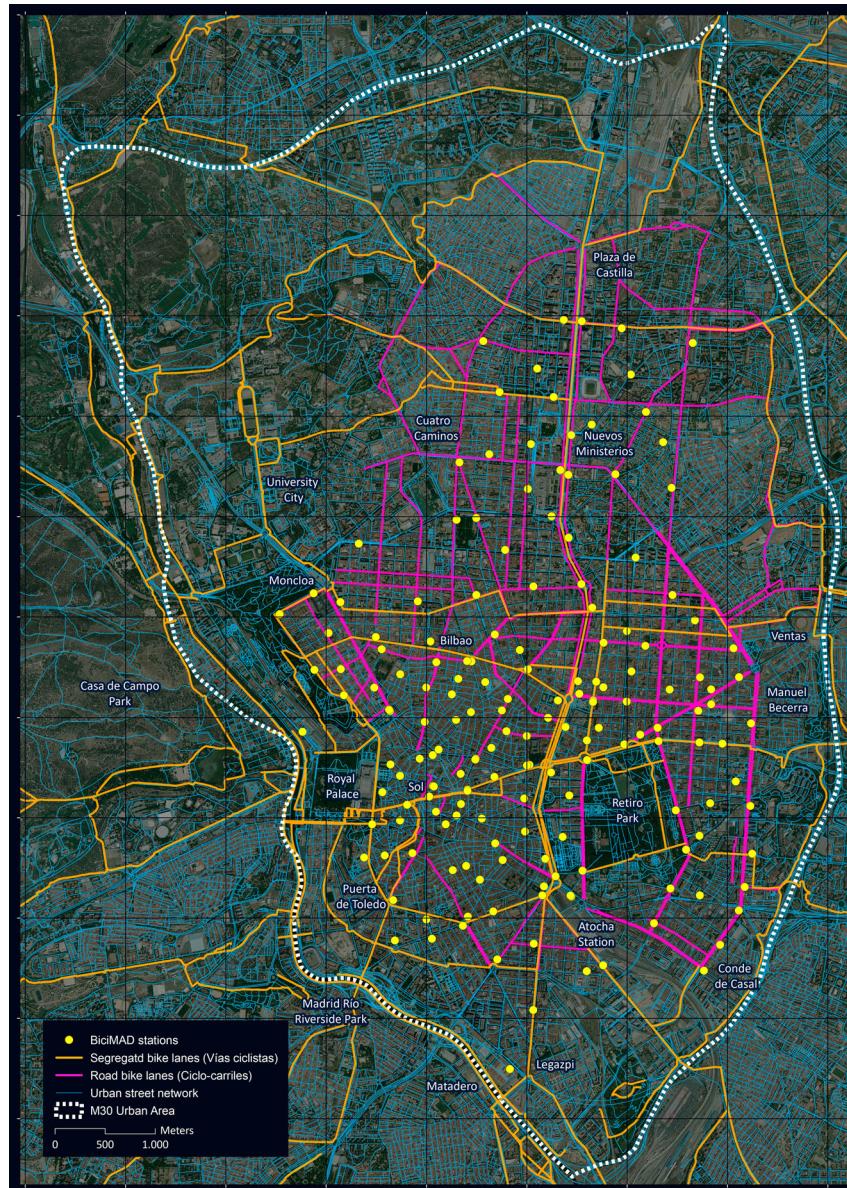


Figure A1. Existing cycling infrastructure in the study area (M30) and BiciMAD stations.