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Understanding micro-mobility usage patterns: a preliminary comparison between dockless bike sharing and e-scooters in the city of Turin (Italy)

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Abstract

Urban areas around the world are experiencing a sharp growth of shared micro-mobility services mainly because of the introduction of shared dockless bikes and, more recently, of e-scooters. Besides understanding who uses these services and why, more studies are needed to understand when and where these services are used and whether their usage patterns differ. This study aims to expand the current state of knowledge about the usage of micro-mobility services by comparing the spatiotemporal usage patterns of a dockless bike sharing (BS) service and an e-scooter service both operating in the city of Turin (Italy). Both visual and statistical approaches are used to analyze and contrast the temporal usage patterns of such services. Usage hotspots are detected by using spatial analysis and contextualized by considering the land use destination.

Results indicate that both micro-mobility services are used to perform short trips, which are mainly occurring on weekdays in the afternoon. Usage peaks suggest that both services primarily fulfill the demand for non-commute related travel, in line with previous studies in other countries. Nevertheless, morning usage peaks of dockless BS service show that the service might also be used for commuting trips to and from university. Usage hotspot detected near to a university district only during weekdays supports this finding. On the other hand, e-scooter trips are mainly concentrated in the city center and in proximity of railway and metro stations, suggesting that, among other purposes, the service is used as a first and last-mile connection to public transport.

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Keywords: micro-mobility; bike sharing; electric kick scooter; usage patterns; KDE

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1. Introduction

During the past few years, many cities around the world have witnessed a sharp increase in the number of shared micro-mobility services, as a consequence of the introduction of dockless bike and e-bike services and, more recently, of dockless electric kick scooters (NACTO, 2020).

Providing an alternative to traditional travel means for short trips, dockless electric kick scooters (henceforth e-scooters) are expected to have relieving effects on congestion and related emissions of pollutants if used to substitute private cars (Hollingsworth et al., 2019; Shaheen and Cohen, 2019). The expected benefits on public transit are twofold: on the one hand, e-scooters may serve as a first or last-mile connection between the origin (or the destination) of a trip and the transit stop/railway station (Fearnley et al., 2020), especially in suburban areas (Smith and Schwieterman, 2018). On the other hand, in areas with a dense public transport network, they are expected to alleviate overcrowded buses, trams, and metro (Ramboll, 2020).

In contrast, the massive introduction of dockless services in a short time has caught unprepared many city administrations, which have been facing safety issues related to the micro-mobility interaction with the other transport means, the need for dedicated infrastructures (cycle path), and complaints about the improper use of public spaces for dockless bikes and e-scooters parking (Gössling, 2020; PBOT, 2018).

Although station-based (or docked) bike sharing systems have a relatively long history (DeMaio, 2009), evidenced by the existing body of literature (Fishman, 2016), less is known about more recent dockless bike sharing (BS) and e-scooters services (Reck et al., 2021). Besides understanding who uses dockless micro-mobility and why, more studies are needed to understand when and where these services are used and whether their usage patterns differ, tackling some of the issues mentioned above and providing reliable policy guidance.

An opportunity to understand more about the usage of this kind of services is offered by the increasing amount of data generated by the GPS tracking devices, which are installed on dockless shared bikes and e-scooters. Such devices allow the end-users to know the real-time GPS position of available means through a smartphone application.

The former studies exploiting positional data analyzed the spatiotemporal usage patterns by considering dockless BS (Reiss and Bogenberger, 2015; Shen et al., 2018) and e-scooters separately (Caspi et al., 2020; Espinoza et al., 2019; Noland, 2019; Zou et al., 2020). Higher usages of dockless BS services were observed near mass rapid transit stations and bus stops, and in areas with a high density of commercial activities (Shen et al., 2018). Main e-scooters usage hotspots have been detected in downtown areas (where restaurants, bars, clubs and shops are located) and in university campus areas (Bai and Jiao, 2020; Caspi et al., 2020; Feng et al., 2020; Jiao and Bai, 2020).

It seems that only a couple of research papers published so far has compared the spatiotemporal dynamics of different micro-mobility services operating in the same urban area: one considered bike sharing only (McKenzie, 2018), and the other docked bike sharing and dockless e-scooters (McKenzie, 2019). In addition, most of the e-scooters' studies were based on data scraped or provided by service providers in North American cities, while empirical studies in other geographic areas are still largely missing. To the best of the Author's knowledge and at the time of writing, the study carried out in Zurich (Switzerland) by Rech et al. is currently the only peer-reviewed article that considers positional data of both docked and dockless bikes and e-scooters services in Europe (Reck et al., 2021).

In Italy, dockless BS services firstly appear in late 2017, whereas some shared e-scooters pilot programs were launched in late 2019 (Ciuffini et al., 2020). Despite the number of shared e-scooter has grown from 4,650 in December 2019 to 27,850 in September 2020 in the whole country (Ciuffini et al., 2020), no articles focusing on their usage within Italian cities have been published yet, to the best Authors' knowledge.

Acknowledging the above-introduced research gap, this study aims to expand the current state of knowledge about the usage of micro-mobility services by comparing the spatiotemporal usage patterns of a dockless BS service and an e-scooter service both operating in the city of Turin (Italy).

The main objective of the study can be achieved by addressing the following two research questions:

- RQ1: What is the usage trend in time during weekdays and weekends? Are there any differences in such trends between e-scooters and bikes? Can these temporal trends be associated with commuting or leisure trips?
- RQ2: Which urban environments and land use patterns are triggering more shared micro-mobility trips?

2. Data

Data used in this study were collected from the available API of two micro-mobility operators in the city of Turin, Italy between October 19, 2020 and March 14, 2021. Within such time period, a set of requests was sent out every 60 seconds to inquire about the availability of means over the whole operational area of the two operators. The resulting dataset counts more than 299M records, each one representing an available bike or e-scooter at the time of the request and therefore containing information on the unique ID of the vehicle, its localization, the timestamp of the request, and the level of charge of the battery (for e-scooters). Neither user information nor her type of subscription (single trip or pass) can be derived from the data.

In order to identify potential trips, records are firstly sorted by ID and timestamp and then consecutive records with the same ID and same GPS positions are discarded, since they represent bikes or e-scooters not in use for that period. On the other hand, consecutive records with the same ID and GPS position even marginally different are combined. About 5.7M displacements of such means were thus identified. Clearly, only a small fraction of these can be considered as an actual trip. Indeed the vast majority of such displacements is less than 10m and it is therefore due to GPS accuracy issues because of urban canyons and the unavailability of satellites (Khatri et al., 2016; Zou et al., 2020). Therefore, a data cleaning procedure is applied to filter out unrealistic trips that meet any of the following criteria:

- trip distance <50m.
- trip duration <2 minutes.
- trip duration >60 minutes for e-scooters; trip duration >120 minutes for dockless BS.
- speed > 20km/h.
- power consumption <0 (the battery has been recharged).

To this effect, the Euclidean distance between each pair of origin and destination points are computed, together with the battery level consumption (only for e-scooters). It is worth noting that a different upper bound for the trip duration is considered, which may influence the results, especially when comparing the two services. Nevertheless, we decided to set those limits according to the maximum number of minutes per ride included in pre-paid passes offered by each service.

The data collection period covers a large time span (146 days), which is however characterized by important limitations to personal mobility dictated by the COVID-19 health emergency (World Health Organization, 2020). In particular, to contrast a new surge in COVID-19 cases, Italian Regions were classified into one of the four groups - red, orange, yellow and white - corresponding to three risk scenarios. Each group foresees specific restrictive measures. The classification of all Regions was periodically updated on the basis of ordinances issued by the Italian Ministry of Health, since the entry into force of this system on November 4, 2020[1].

As different restrictions impact daily activities, changes in travel demand and in the use of transport means, including shared mobility (Ciuffini et al., 2020), are expected accordingly. Since the aim of this study is not to compare the usage pattern under different COVID-19 restrictions but rather to provide first exploratory analyses and comparison of two shared micro-mobility services, we decided to focus only on the 57 “yellow days” when restrictions were relatively eased, given that only seven days within the observation period could be considered as “white”.

Lastly, due to some technical issues in the data collection process (server breakdowns), three days are furtherly removed. As a result, 54 days under yellow area restrictions are finally retained accounting for 32,242 trips in total.

3. Methodology

In order to analyze and compare the usage patterns of bike sharing and e-scooters, both visual and statistical approaches are used. In particular, to determine temporal usage patterns of dockless BS and e-scooters and thus answering to RQ1, trips identified through the data cleaning procedure are grouped in hourly timeframes according to their starting time (timeframe 0 includes trips that started between 0:00 and 1:00 AM), the day of the week (weekdays and weekends), and the service (bike and e-scooter). Relative frequencies are then calculated on an hourly basis by

[1] http://www.salute.gov.it/portale/nuovocoronavirus/homeNuovoCoronavirus.jsp - Accessed March 14th, 2021

dividing the trip counts of each timeframe by the total number of trips performed with the considered service during the analysis period. The Two Proportion Z-Test is then applied to identify any significant differences between the hourly usage of the two services.

To explore the spatial dimension of micro-mobility services and identify the core operating areas (RQ2), trips origin and destination of each service are analyzed through the two-dimensional kernel density estimation (KDE) tool available in QGIS (QGIS Development Team, 2019). KDE is a density-based algorithm for hotspot identification that has been widely used in several fields such as criminology (Anselin et al., 2000), road safety (Bassani et al., 2020), and also in a previous study on sharing mobility (McKenzie, 2020). The two parameters of KDE that need to be defined are the kernel function (or decay function) and the bandwidth (or smoothing parameter). While the type of kernel function does not significantly affect the output, the bandwidth instead strongly affects the results because it directly controls the spread of each kernel. Therefore, using a quartic shape kernel function, we performed different KDE using bandwidth ranging between 50m (corresponding to the minimum trip distance) and 1000m; we observed that smaller bandwidth produces very small and more distributed clusters while larger bandwidth reduces the granularity of the estimation grouping distinct clusters. Thus, we finally opted for a kernel bandwidth of 500m since, for the purpose of the study, we are more interested in identifying principal clusters of usage rather than the precise location of small clusters. The density surface coming out from the KDE was stored on a raster dataset at a spatial resolution of 5 m by 5 m for each micro-mobility service. The resulting usage hotspots are then visually compared, also considering the land use destination.

4. Results

4.1. Descriptive statistics of micro-mobility trips

Descriptive statistics of the observed trips with dockless BS and e-scooters during the analysis period are reported in Table 1. Within a period of 54 days, 6,878 trips were identified with dockless BS (127 trips/day) and 25,364 with e-scooters (470 trips/day). However, this is not necessarily meaning that e-scooters were used so much more, since the above-introduced filters had a stronger impact on BS trips given a lower quality of the related GPS data, which led to inconsistencies between travel times and travel distances and subsequent unrealistic speed values. Thus, the figures in the table should be considered as sample data.

Table 1. Descriptive statistics of bike sharing and e-scooters trips

	bike sharing (*N=6,878*)			e-scooters (*N=25,364*)		
	Trip distance (m)	Trip duration (minutes)	Trip speed (km/h)	Trip distance (m)	Trip duration (minutes)	Trip speed (km/h)
Mean	1349.7	23.0	5.9	1445.7	15.5	6.5
Std. Dev	1122.5	26.1	4.1	1110.9	10.4	3.8
Min.	50.0	2.0	0.1	50.0	2.0	0.1
25%	485.0	7.0	2.4	616.0	8.0	3.2
50%	1082.0	13.0	5.7	1155.0	13.0	6.4
75%	1941.8	27.0	8.1	2009.0	21.0	9.4
Max.	7777.0	120.0	20.0	8512.0	60.0	19.6

Looking at the trips distribution during the analyzed period, we observed a similar usage trend characterized by higher usage of both services during weekdays than on weekends. In particular, dockless BS shows an average of 142 daily trips during weekdays against 95 daily trips on weekends. Similarly, e-scooter usage range from an average of 486 daily trips on weekdays to 433 daily trips on weekends, in contrast with previous studies where ridership peaked on Saturday (Bai and Jiao, 2020; Younes et al., 2020). It is however hard to assess to which extent the above-mentioned COVID-19 restrictions are influencing our result.

Considering trips characteristics, both dockless BS and e-scooters are used to perform short trips, with an average distance of 1.3 and 1.4 kilometers, respectively, which is in line with studies carried out in other countries (Bai and

Jiao, 2020; Jiao and Bai, 2020). However, although average trip distances (measured as Euclidean distances between origin and destination points) are very similar, the average trip duration significantly differs between the two services ($t=36.2$, $p<0.001$). BS trips last 23 minutes on average and are characterized by an average speed of 5.9km/h. On the contrary, e-scooter trips have an average duration of 15.5 minutes and an average higher speed of 6.5km/h. Interestingly, despite 50% of trips last less than 13 minutes (median value) in both cases, the high share of long trips in bike sharing strongly affects the mean value (25% of trips have a duration between 27 and 120 minutes).

4.2. Temporal distribution

The daily trips distribution on weekdays and weekends of dockless BS (left column), e-scooter trips (central column), and their difference (right column) are showed in Fig. 1.

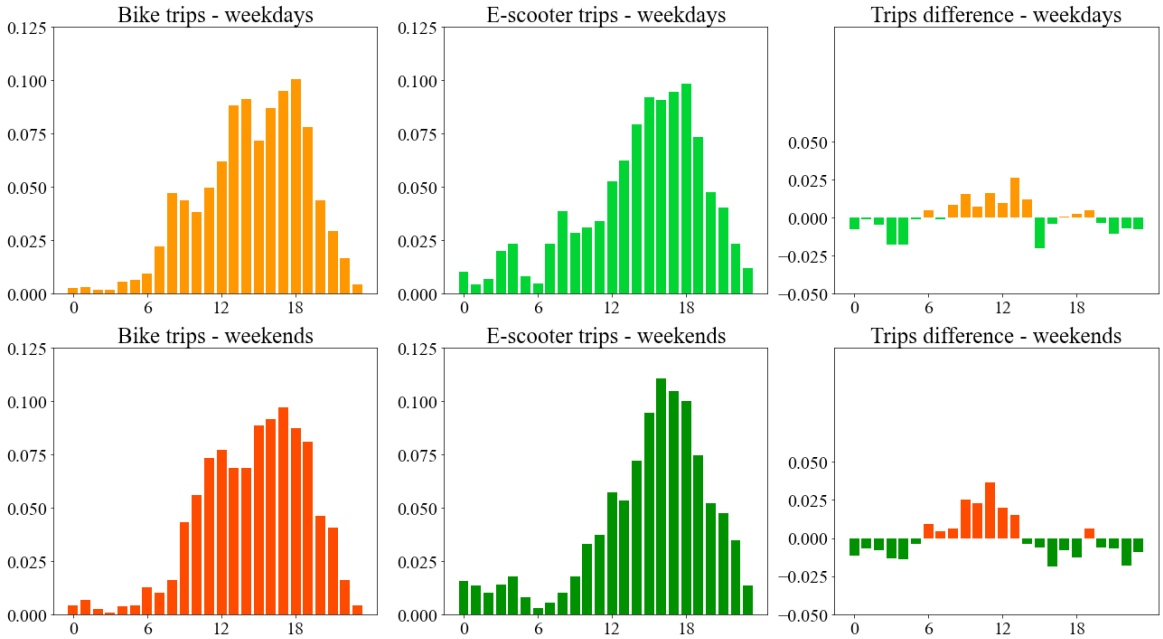

Fig. 1. Trip origin hourly distribution on weekdays and weekends (relative values)

Considering the trips distribution on weekdays, dockless BS shows a peak of usage between 6-7 PM, accounting for about 10% of the daily demand. Other peaks of usage can be observed in the early afternoon (1-3 PM) and in the morning (8-10 AM), albeit the latter accounts for 5% of the daily demand.

On the other hand, e-scooter trips distribution is characterized by a morning peak between 8-9 AM, a decline between 9 and 12 PM, and then higher usage rates between 12 PM and 7 PM. The peak of usage of e-scooters reflects the one of dockless BS, not only in terms of time (both occur around 6-7 PM) but also in terms of magnitude; indeed the two proportions do not significantly differ ($z=0.476$, p-value=0.634).

Looking at the trip distributions' differences, a significantly higher proportion of trips is performed with dockless BS between 8 AM and 3 PM, whereas the opposite occurs between 3 and 5 PM. Furthermore, the proportion of trips is higher for e-scooters during night hours (11 PM – 5 AM), albeit these usage patterns are not easily interpretable. In fact, due to the COVID-19 restrictions, only specific trips can be performed in such hours; therefore, they might be associated either with such trips or to service operations not filtered out through the data cleaning procedure.

Interestingly, the morning and the evening usage peaks showed on weekdays correspond to the peaks of usage of motorized transport means (private cars and public transport) in the city (Agenzia per la Mobilità Metropolitana e Regionale, 2015), suggesting that both micro-mobility services may serve commuters. However, the midday peak of dockless BS and high usage rates in the afternoon of both services suggest that they are also used to satisfy many other trips purposes.

Trips distributions on weekends partially follow those showed on weekdays. The differences between trip proportions almost keep the weekdays' trend, with a high proportion of dockless BS trips between 6 AM and 2 PM and around 7 PM. However, in weekends' distributions, both micro-mobility services do not show the morning peak, while both evening peaks of usage occur earlier (4-5 PM e-scooter, 5-6 PM dockless BS).

4.3. Spatial distribution

In line with the temporal analysis, the spatial dimension of the micro-mobility usage patterns is analyzed by separately considering the two services during weekdays and weekends. Heatmaps are obtained by coloring the density surface produced through KDE with individual colors depending on density intervals. Since the two services presented different trip volumes, intervals were set according to the elevation of the density surface with respect to the mean value (M). In particular, five density intervals were considered: below the mean (light blue), above the mean value (green) and above 1, 3, and 5 times the standard deviation (SD) over the mean (yellow, orange, and red, respectively).

Fig. 2 shows the heatmaps of the trips performed with dockless BS (on the left) and e-scooters (on the right) during weekdays; to make the reader aware of the different coverage of the services in the city, the limits of each service operational area as February 2021 are marked with thick black lines.

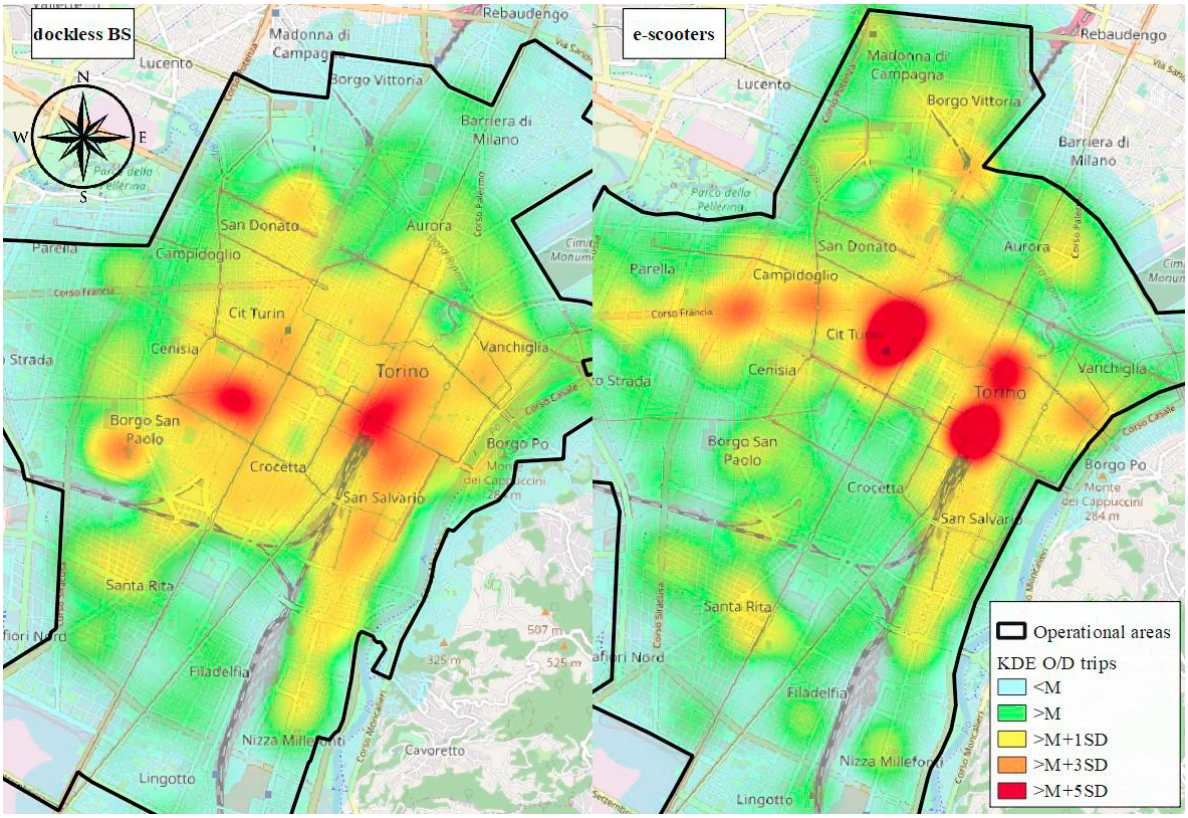

Fig. 2. Usage hotspot of dockless BS (left) and e-scooters (right) during weekdays

Although the operational areas of the two micro-mobility services are largely overlapping, the spatial distribution of the usage patterns is rather different.

The main e-scooters hotspots (where the density function values are greater than 5 SD over M) are located in the city center and close to the two main railway stations of the city, Porta Susa (near to Cit Turin neighborhood) and Porta Nuova (immediately above San Salvario neighborhood). Other important hotspots (M+3SD) can be observed in Vittorio Veneto square (below Vanchiglia and next to the Po river), in the Northern part of the city (below Borgo Vittoria), and moving in South-West direction from the Cit Turin neighborhood (along Corso Francia).

Interestingly, most of the e-scooter hotspots are in proximity of public transport stops: Porta Nuova and the area next to Porta Susa are in fact two important mobility hubs, where the M1 metro line and several bus lines interchange with the railway stations. Likewise, the hotspots along Corso Francia overlap two metro stops, and the one below Borgo Vittoria coincides with the Dora metropolitan railway station. These spatial patterns may therefore highlight some relationship between e-scooters and public transport services.

The presence of hotspots in the area in front of Porta Nuova and within the city center also suggests that e-scooters might be used to satisfy utilitarian trips. These areas are connected by a commercial street (via Roma) where many shops, bars, restaurants and business offices can be found.

Dockless BS hotspots (M+5SD) are detected near the Politecnico di Torino university (between Cenisia and Crocetta neighborhoods) and next to the city center, in the area in front of the Porta Nuova railway station. Other hotspots (M+3SD) are visible in San Salvario, Cit Turin (near to Porta Susa railway station), and Borgo San Paolo neighborhoods. Jointly considering the spatio-temporal trips distribution, we can infer some dockless BS usage pattern. More specifically, hotspots detected in the university area and railway station suggest that, among other types of activities, dockless BS might be used for commuting trips to and from university. This deduction is supported by the temporal usage peak shown in the morning hours (8-10 AM), in the early and late afternoon (1-3 PM and 6-7 PM), which may be related to the classes' start/end time. Moreover, the hotspot in Borgo San Paolo neighborhood supports this thesis since one of the residences is located in that area.

As per trips distribution of e-scooters, the hotspot in front of the Porta Nuova station and its connection to the city center suggest that dockless BS might be used to access public transport services to satisfy utilitarian trips. The latter is also confirmed by the other main usage hotspots (orange areas), which are situated in mixed land use areas, where commercial, business, and residential districts coexist.

The usage hotspots of both micro-mobility services during weekends are rather similar to those observed for weekdays, especially considering e-scooters, and related maps are not reported here to save on space. The Vittorio Veneto square area becomes more attractive during weekends, while Dora metropolitan railway station is less frequented. In contrast, the dockless BS hotspot observed in proximity of the Politecnico di Torino university during weekdays is not visible on weekends, again supporting our deduction about the usage of dockless BS for educational commuting trips. During weekends the hotspot is moved between the Cenisia and Borgo San Paolo neighborhoods, where many of the Politecnico's students live.

5. Conclusions

In this study we investigated the usage of two dockless micro-mobility services operating in Turin by exploiting the data available through the service APIs. Since data collection occurred in a period characterized by important limitations to personal mobility dictated by the COVID-19 health emergency, the analysis period consists of 54 days where restrictive measures were less severe.

In such period, the usage of both dockless BS and e-scooters in Turin is characterized by short trips mainly occurring on weekdays. The highest share of trips occurs in the afternoon, with a peak of usage around 6-7 PM, suggesting that both services primarily fulfill the demand for non-commuting trips, in line with the findings from other countries (McKenzie, 2018; Noland, 2019; Zou et al., 2020). However, the BS service morning peak suggests that this service might be also used for commuting trips to and from university. This result is confirmed by the usage hotspots detected through the spatial analysis. It is worth noting that, despite the morning peak represents about 5% of the daily travel demand, it occurs in a period in which most university classes are remotely hosted and the university access is limited to university staff and students involved in laboratory activities. Therefore it is likely that this peak would be even sharper in ordinary conditions.

On the other hand, e-scooter trips are mainly concentrated in the city center, a mixed land use area where many bars, restaurants, shops but also offices can be found, thus suggesting that the service is used to satisfy utilitarian trips. Moreover, e-scooters usage hotspots identified in the proximity of railway and metro stations may indicate the use of the service as first, last-mile connection to public transport.

Interestingly both services are less used during weekends, partially in contrast with previous studies on both kinds of services in other cities. This may suggest that the services are used for other kinds of trips rather than recreational ones, however we cannot generalize this finding since it may be influenced by the peculiar period under analysis.

Despite the data cleaning procedure, the identified trips should be considered as samples and there could still be some errors, i.e. trips performed by the service provider for maintenance or fleet relocation. Additionally, we

considered one e-scooter operator out of the seven available in the city, even if their operational areas are essentially overlapping, therefore the services might be used in the same way. However we did not consider strategic decisions of the operator concerning the availability of e-scooters in specific areas, which might clearly affect spatial usage patterns. Finally, due to the pandemics, these results cannot be generalized. A future study will investigate the usage patterns of both kinds of micro-mobility services under different COVID-19 restrictions to address this shortcoming.

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