ARTICLE IN PRESS

Journal of Transport Geography xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset

Marie Vogel [a], Ronan Hamon [b,c], Guillaume Lozenguez [b], Luc Merchez [d], Patrice Abry [b], Julien Barnier [a], Pierre Borgnat [b,*], Patrick Flandrin [b], Isabelle Mallon [a], Céline Robardet [c]

[a] Université de Lyon, CNRS, Centre Max Weber (UMR 5283), ENS de Lyon, France
[b] Université de Lyon, CNRS, Laboratoire de Physique (UMR 5672), ENS de Lyon, France
[c] Université de Lyon, CNRS, LIRIS (UMR 5205), INSA Lyon, France
[d] Université de Lyon, CNRS, Environnement, Ville, Société (UMR 5600), ENS de Lyon, France

ARTICLE INFO

Keywords:
Bicycle-sharing systems
Urban mobility
Cyclist typology
Vélo'v in Lyon
Pro-cycling strategies

ABSTRACT

Vélo'v have been available in Lyon, France, since 2005, and are one of the first major public bicycle sharing systems (BSS) implemented in Europe. With up to 7 million trips in 2013 and around 50,000 annual users plus occasional users, Vélo'v have increased bicycle use in the city by 50%. Analysing a database gathering both bicycle movement and user data for the calendar year 2011 provided by the operator, we concentrate our analysis on Vélo'v users. We characterise user mobilities and produce a user typology based on cluster analysis, relying on intensity and on annual and weekly temporal patterns. The proposed analysis, which creates user profiles from patterns, contributes to a close-reading of the interplay between BSS and other transports as well as to an improved understanding of conditions leading to a wider use of bicycles in cities.

1. Introduction

Overviews of the existing research on bicycle sharing systems (BSS), as presented in Fishman et al. (2013) and O'Brien et al. (2014), inform us of both the rapid spread of BSS worldwide and the amount of research publications dedicated to the new device. The success of BSS cannot be questioned: while they were almost non-existent a decade ago, at the end of 2013 there were 600,000 public bicycles located in 600 cities across the world according to the ITDP Bike-share planning guide (2013).

In the same way, studies on the topic have multiplied and deal with technical aspects as well as with the impact of this new means of transport. Nevertheless, according to Fishman et al. (2013), many issues – such as current cycling patterns of BSS users or multimodal travel – are hardly looked into. Third generation BSS (Shaheen et al., 2010) are recent means of transport using smart card technology. They produce station- or system-level data, which enables the study of actual trips, mostly studied at the levels of the stations, or of the system. Having the opportunity to cross user data with movement data offers new perspectives to the study of mobility behaviours at the individual level, as indicated in Beecham and Wood (2013). However, the potential of this analytical perspective still remains unexplored.

The current paper follows a similar approach. Through the analysis of a dataset provided by the operator, including bicycle movement and anonymous user data for the calendar year 2011, we concentrate on Vélo'v users of the BSS in Lyon, and their actual practices. We will characterise their mobilities and offer a typology of users based on the intensity and on the temporal patterns of usage. One purpose of the developed typology of BSS cyclists is to make a contribution to the comparison with ordinary cyclists, and to the analysis of active (walking, cycling, with BSS) and non-active (public transport) urban mobilities and their publics.

The paper is organised as follows. Section 2 provides a review of earlier research literature and positions our research. Section 3 presents the Lyon case study and dataset. Section 4 provides a general overview of users and significant habits for the subsequent analysis of the typology. The statistical method of clustering and the typology of annual users are discussed in Section 5, while

* Corresponding author. Address: Laboratoire de Physique, ENS de Lyon, 46 allée d'Italie, 69464 Lyon cedex 07, France. Tel.: +33 4 72 72 86 91; fax: +33 4 72 72 80 80.

E-mail addresses: marie.vogel@ens-lyon.fr (M. Vogel), ronan.hamon@ens-lyon.fr (R. Hamon), guillaume.lozenguez@ens-lyon.fr (G. Lozenguez), luc.merchez@ens-lyon.fr (L. Merchez), patrice.abry@ens-lyon.fr (P. Abry), julien.barnier@ens-lyon.fr (J. Barnier), pierre.borgnat@ens-lyon.fr (P. Borgnat), patrick.flandrin@ens-lyon.fr (P. Flandrin), isabelle.mallon@univ-lyon2.fr (I. Mallon), celine.robardet@insa-lyon.fr (C. Robardet).

http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005
0966-6923/© 2014 Elsevier Ltd. All rights reserved.

Section 6 discusses results both for annual users and for short-term users. Finally, Section 7 concludes the paper.

2. Background: analysing cyclists' and BSS users' practices

Until quite recently, there were relatively few studies on bicycle users (except in countries such as Denmark and the Netherlands), which is consistent with the modal share of this means of transport at the end of the 20th century – 2.7% in France in 1994 (Papon, 2012). The worldwide development of policies promoting active travel (walking and cycling) is combined with renewed attention to actual or potential cyclists. Taking into account the heterogeneous characters of cyclists and their cycling patterns, studies in social sciences have mainly concentrated on producing typologies on the basis of declarative data (surveys or interviews).

The overview sketched out by Dill and McNeil (2013) clearly shows that typologies of cyclists are built from two types of dimensions, i.e. the characteristics of their practice (intensive or occasional, seasonal or non-seasonal) and actors' motivations and preoccupations. Thus, Heinen et al. (2010) in the Netherlands and Bergstrom and Magnusson (2010) in Sweden rely on the variations in intensity and in modes of practice in order to classify cyclists (full-time cyclists, part-time cyclists, winter cyclist, summer-only cyclist, infrequent cyclist, and never cyclist), to identify differences in behaviour between these groups and to link them to factors influencing the choice to commute by bicycle. In the case of Montreal cyclists, Damant-Sirois et al. (2013) produce four distinct cyclist types (dedicated cyclists, path-using cyclists, fairweather utilitarians, and leisure cyclists) that also integrate the intensity of practice.

The summary report produced by the Centre d'Etudes sur les Réseaux, les Transports, l'Urbanisme et les constructions publiques (CERTU) of the French Ministry of Transport (2013), on bicycle users and bicycle trips in urban contexts in France, uses similar analytical categories. The study compiles the results of fourteen mobility surveys conducted between 2006 and 2010 in fourteen French cities. Bicycle practices are differentiated according to their users' characteristics (gender, age and social background), the intensity of practice and motives of travel. The study gives a differentiated picture of bicycle users and their practices. Ravalet and Bussière (2012), compare Lyon and Lille cyclists' practices and their evolution in the past fifteen years, and come up with rather similar data. Other typologies focus on limited aspects such as safety (related perceptions and behaviour), taking into account cycling patterns in their variables (Christmas et al., 2010). The latter study noted a significant diversity within the population cycling for utility (unlike for leisure).

Despite their various objectives, these typologies show a strong segmentation of cyclists in terms of intensity and cycling patterns, and the considerable differences in motivations and expectations. Studies also show the strong interdependence between different choices in transport modes.

Since the first BSS were set up, studies have been conducted to focus on this new kind of bicycle users. For instance, some researchers (e.g., Shaheen et al., 2012) explored the nature of the substitution with other modes of transport (walking, public transport, cars) in a comparative way, and BSS users' preferences in terms of infrastructure, their safety concerns, the types of uses (commuting or leisure), and multimodal travel (Fishman et al., 2013). Similar studies were completed in Dublin (Murphy and Usher, Forthcoming), in Montreal (Fuller et al., 2011; Bachand-Marleau et al., 2012), in North-American cities (Shaheen et al., 2010) and in Hangzhou, China (Shaheen et al., 2011). Globally, they described the users' socio-demographic profiles and explored more directly the reasons for choosing this new means of transport. They draw a relatively comprehensive picture of BSS users across the world. In the case of Lyon, studies on news BSS users conducted by local authorities and the operator at the time of the system's implementation (Grand Lyon, 2006) remain rather superficial. Such studies also use survey data, or various levels of detail: they grasp patterns of travel on a declarative basis without resorting to BSS data.

From another angle, researchers using datasets on BSS movements have mostly sought to analyse temporal variations and spatial mobility flows at an aggregated level (Maizia and Dubedat, 2008; Lathia et al., 2013; Borgnat et al., 2011 and 2013), taking into account dependency upon infrastructures (Nair et al., 2013), or the advantages of BSS as compared to other modes of transport, such as speed for instance (Jensen et al., 2010). They seldom have user data, nor do they link movements to user data. Buck et al. (2012) have used such data in order to compare the profile of CaBi users – Capital Bikeshare, the BSS in Washington, DC – with ordinary cyclists: they conclude that differences are notable. Morency et al. (2011) make a joint use of dataset aiming primarily at characterising the Montreal BSS in an engineering perspective. Ogilvie and Goodman (2012) use the London BSS movement data together with user data with a view to analysing social inequalities in BSS access, as do Beecham and Wood (2013), who look into gender differences in BSS use (in terms of space and intensity). To our knowledge, these are the first papers using such datasets in a study of BSS use at the individual level.

The numerous typologies of cyclists, as well as studies on BSS users, draw profiles of cyclists which vary importantly, both in terms of motives and use claims, and which are a striking contrast with the average picture of the urban cyclist. This research contributes to debate concerning, among others, BSS users and gender, age and income, BSS impact on modal choice, users' perception of safety. However they make only marginal use of operators' databases of actual journeys. Therefore it seems interesting to look deeper into the study of users and their practices by relying on actual movement databases and characterising profiles of patterns of usage at an individual level. To what extent do the observed lines of differentiation in practice for cyclists also exist among BSS users? To what extent is there a continuity in cycling patterns between BSS and ordinary bicycles, both considered as modes of travelling? BSS have contributed to the return of bicycles in cities and are one of the forms of public intervention that encourages it. However, the study of the similarity of uses at the individual level has not been explored much, and could benefit from being developed.

At the same time, using these databases in a user-centric perspective is a way to shift the questions asked in BSS analysis from a systems standpoint (thus multiplying the comparison of various ratios) to a vision whereby the role of social factors determining personal as well as collective choices (those that are defined by the articulation of the transport systems within a given urban area) can be reintroduced.

3. Vélo'v BSS: case study and dataset

Like many bicycle sharing systems, Vélo'v is both an autonomous system exclusively located in a restricted area (the Lyon/Villeurbanne downtown area) and a sub-system of a public transport service mapping a broader territory – the Urban Community of Lyon or "Grand Lyon" (Greater Lyon metropolis). Consequently, users and their cycling patterns should be analysed with reference to both configurations. The downtown area coincides with the limits of two municipalities Lyon and Villeurbanne – and the BSS station network is confined between these cities' limits.

The "Grand Lyon" comprises 58 municipalities and more than 1.3 million inhabitants. Half of the population lives in one of the two main municipalities, Lyon (485,000 inhabitants) and Villeurbanne (145,000 inhabitants). The demographic dynamics of the

Please cite this article in press as: Vogel, M., et al. From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset. J. Transp. Geogr. (2014), http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005

metropolis are characterised by a densification of the central part of the "Grand Lyon" area, a substantial growth of the population since 2000 and a strong renewal. Indeed almost 30% of the population in the 2006 census did not live in Lyon five years earlier (Authier et al., 2010). The downtown area – Lyon, and to a lesser extent, Villeurbanne – has distinctive features: its population is younger and more qualified than the average in France's other large cities (people under 45 account for 66% of the population as opposed to 58% in Marseille) and one-person households are very common (one in two in Lyon as opposed to one in three on a national level). Lyon is a city of senior and junior executives, as well as employees. These three categories, all of equal weight, make up 80% of the working population. There is a large proportion of students, who made up 18% of the 15–64 year olds in 2010 in Lyon (Marseille 10%, Paris 10.5%, INSEE 2010). The city of Lyon differs from the rest of the urban area (i.e. the Urban Community of Lyon) since it comprises the highest proportion of highly educated and executive workers. Nevertheless, the residential area of the city centre is not homogeneous and strong social disparities exist. At the scale of the "Grand Lyon" area, and especially for the municipalities closed to the city centre the territory is marked by a clear East/West asymmetry. Indeed – lower social classes and immigrant populations are mainly located in the East. Such socio-spatial inequalities have increased over the past twenty years (Authier et al., 2010). This urban social space hosts Lyon BSS and its users, and partially determines the demand.

3.1. Vélo'v, a part of the urban transport system

The Vélo'v system, which was set up in Lyon in 2005, is one of the first major public BSSs in Europe. It is a good example of third generation BSS (Midgley, 2011). 343 stations and 4000 bicycles have been introduced since 2007, and the system rapidly became successful, with more than 5.5 million journeys made annually in 2006 and 7 million in 2013. The Vélo'v system is firmly integrated into the public transport network, and has also strengthened the return of bicycles into the city.

Vélo'v stations are mostly located in the centre of the urban area and cover the nine districts of the municipalities of Lyon and Villeurbanne (see Map 1). The distance between two stations is an average of 255 m and at most 850 m (Merchez and Rouquier, 2011). Each station can park between 10 and 40 bicycles. As the spatial distribution of Vélo'v stations is uneven, the offer is unsurprisingly concentrated near multimodal transport interchange areas (e.g., railway and subway stations) and universities. A comparison between the number of potential BSS users (15–75 year olds) and the number of stations reveals that some districts are better equipped than others. While this unequal access to the system can be explained in some cases by the presence of geographic barriers (hills, motorways, etc.), in other cases, these contrasts reproduce mostly economic inequalities within the city, with the most socially degraded districts (the 8th and 9th districts) having the poorest access to Vélo'v BSS.

Vélo'v bicycles can easily be rented and used for a one-way journey. Thus, the rent pattern does not only depend on the population living near the station, it also depends on the other available transport modes connected to the Vélo'v network. In our case, Vélo'v is largely integrated into the public transport network, especially since there is no requirement to wear a helmet. The Vélo'v fare policy all but equates the system to a free extension of the public transport network, up to the point that the same pass can be used to access both public transport and Vélo'v. In 2011, the annual membership fee (the only existing subscription package) was 15 euros per year, and offered 30 free minutes per journey for an unlimited number of journeys. Whereas in Montreal, for instance, the annual membership costs 80 dollars and the system is open only from April to November, in Lyon an annual membership costs 15 euros. The price for daily (i.e. 24 h) and weekly (i.e. seven consecutive days) membership is also low (respectively 1 and 3 euros). A long-term public transport or regional train pass holder gets an extra 30 min free per trip. This reduced membership fee, and the 30 min bonus encourage far more subscriptions to both public transport and BSS than other BSS.

The Lyon BSS is well connected to the public transport system both in terms of spatial organisation and fares policy. It concentrates around a small perimeter of intense economic and social activity, and as such its rapid success can be explained with reference to the profile of the resident population (students, qualified urban workers, one-person households). After a rapid growth over the first two years of its existence, the Vélo'v system is now stable and the numbers of journeys and memberships are slowly increasing. Hence, Vélo'v is a good example of a successful integration of the BSS to its urban environment.

3.2. Data

The purpose of this study is to characterise Vélo'v users through the description of their general profile, of their use of the BSS and through a typology based on the intensity of BSS use and actual cycling patterns throughout a whole calendar year, in this case 2011. For that matter, we use bicycle movement and user data similar to those used by Beecham and Wood (2013) in their study of gendered practices in the London BSS. For bicycle movements, each record provides details of the location and the time of the beginning and the end of the journey, and is indexed to a single membership (annual, weekly or daily). Annual memberships carry information about the subscriber (age, gender, postcode), while no information on the users can be gathered from short-term passes (daily or weekly). The use of these wholly anonymised dataset allows the study of users' profiles at the level of individual memberships (annual, weekly, daily), even though complementary information is only provided for annual members.

In order to account for journey patterns and not only bicycle rent, the data we analyse does not include journeys shorter than 3 min – often defective bikes quickly replaced at another station – nor longer than 24 h. Likewise, among annual members, we have excluded "suspicious" users (24 in total) presenting unrealistic practices or ages. In total, our corpus includes, for 2011, 6.5 million movements (see Table 1).

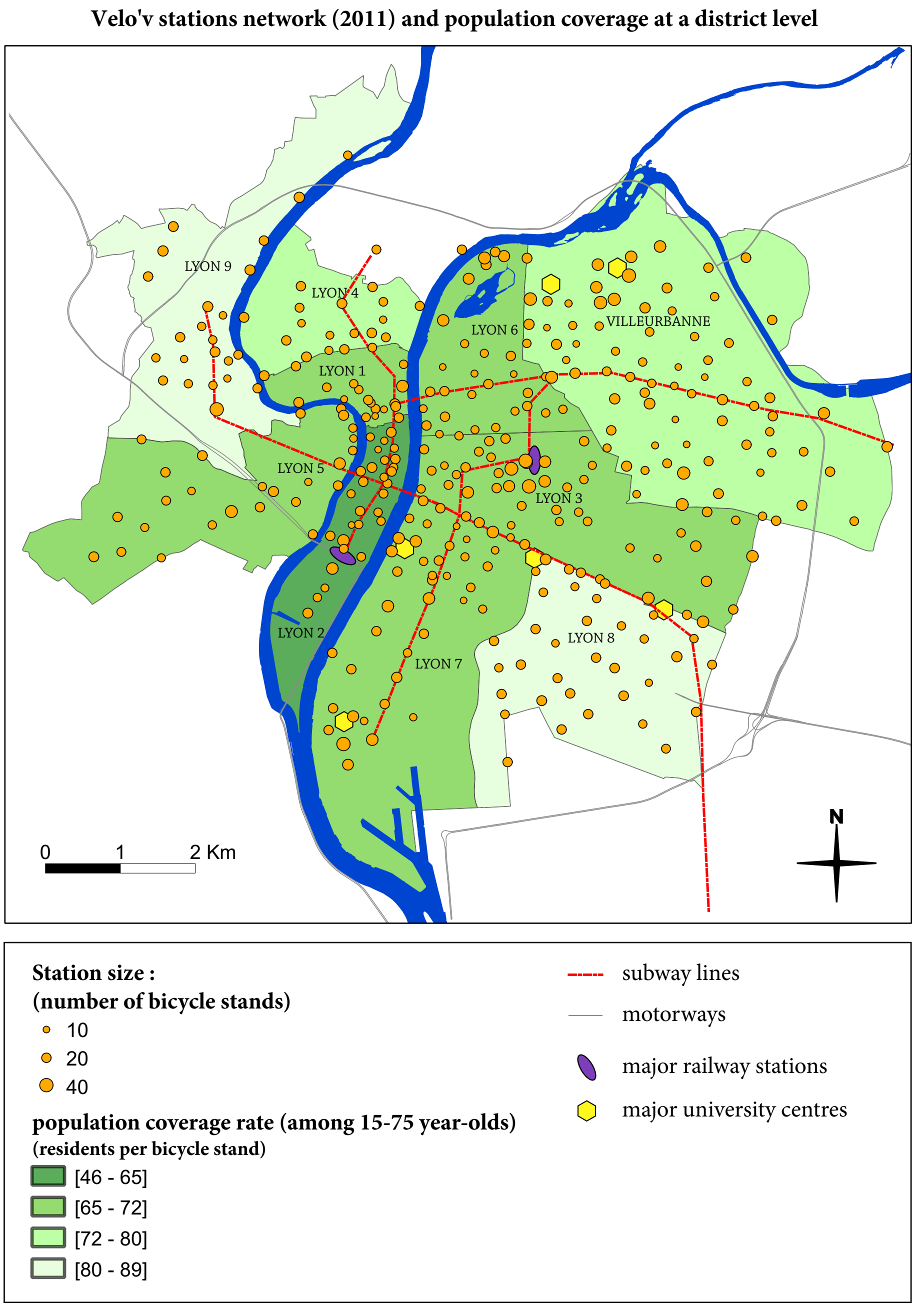
With such data, it is possible to differentiate types of "actual" uses individually linked to types of membership. As a first step, we compare actual cycling patterns of annual and short-term users, and as a second step, we focus on an analysis of a typology of the annual users. Movements in connection with annual memberships make up over two thirds of annual movements in the whole system. Additional data on members makes it possible to build a basic typology of users and use of the Lyon BBS according to actual practices and to link them to demographic and spatial information.

4. Vélo'v users and their use patterns

The dataset on annual members contains information (age, gender and postcode) that gives a general overview of users. We complete such profiling with a comparison of the temporal cycling patterns of different types of users (daily, weekly and annual users).

4.1. A group portrait of annual Vélo'v members

The population of annual members of the Vélo'v system has reached approximately 50,000 people. First of all, they can be



Map 1. Vélo'v station network (2011) and population coverage at a district level.

Table 1
Number of movements by type of subscription.

	Number of movements	Percentage of total movements	Average number of movements by subscription
Short-term daily subscription	1,169,362	18.0	1.7
Short-term weekly subscription	960,565	14.8	9
Annual subscription	4,363,500	67.2	86
Total	6,493,427	100	

characterised by their spatial distribution. Research shows that users of a given station tend to live close to this station, yet proportions vary. In the London case for instance, in 2011, the BSS network area covers 65 km^2 and only one third of the members are living within 500 m of a BSS docking station (Ogilvie and Goodman, 2012). In London still, (Beecham and Wood, 2013) consider the number of membership holders living within a perimeter of 5 km away from a station, which amounts to 37% of total members (i.e., 50,000 out of 135,000 members). In Lyon on the other hand, the concentration of membership holders living within the area covered by the BSS is far denser. 84.2% of users live in the downtown area (62 km^2), 7.3% of them live outside the limits of the BSS network but in the “Grand Lyon” area, and 8.5% come from further away (see Map 2). Generally, the proportion of active subscribers decreases with the distance between their residence and the Lyon central area. There are, however, exceptions, such as the cities located West or Northwest of Lyon: they are better integrated into the Vélo’v system in terms of users, despite the fact that they are not well-connected to Lyon city centre due to topographical constraints (hills). The socio-professional profiles of the residents of the Western and the Eastern municipalities (broadly higher social classes for the former and lower social classes for the latter) are likely to explain such variations. Several surveys have shown that Vélo’v cyclists are mainly students, executives or stable employees, which are the majority of socio-professional profiles of the residents of Western municipalities.

The districts within the municipality of Lyon which comprise most users generally have the largest populations (the 3rd district and Villeurbanne). The penetration of Vélo’v in the population varies by a factor of three, and is likely to be a cross effect between network disparities (see Map 1) and demographic social profiles.

Considering the spatial distribution of users, there is no distinct contrast between men and women – contrary to the London study (Ogilvie and Goodman, 2012). Female members live downtown more often than male subscribers (86.3% as opposed to 82.6%). Conversely, active male members living outside the centre are proportionally more numerous. This fact can be explained by a more important mobility of 35–49 year-old men and by biases induced by the addresses of students, in majority male, which are more often the addresses of parents living outside the city. In the downtown area, women are almost as numerous as men in some districts (1st, 7th). By comparing these figures with the resident population, we can notice that some districts, however, are rather unbalanced. For example, in Villeurbanne, two women for three men are Vélo’v users, which might be explained by the location of a scientific campus where the number of male students exceeds that of female students.

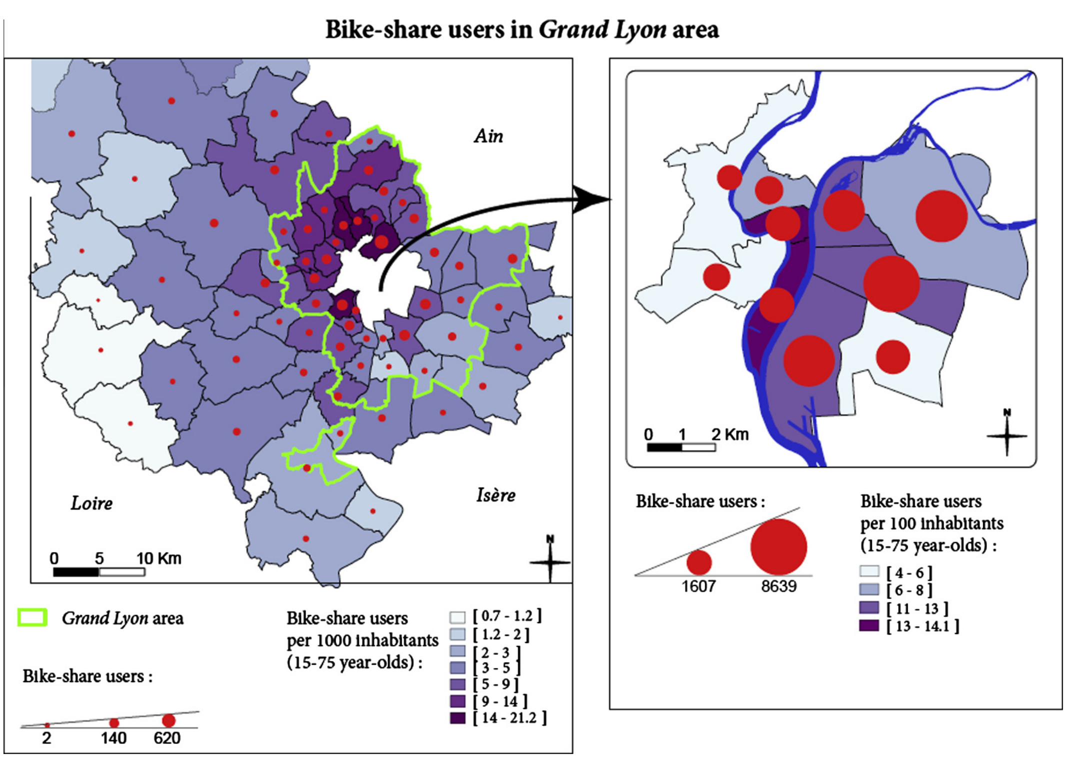
The second way of characterising this group is to consider its members as users of the public transport network. In fact, active members of the Vélo’v system are mostly also members of the city’s public transport (52.4%) or regional trains (4.6%) networks, bringing up to 57% the percentage of BSS users who can use Vélo’v in connection with other means of public transport. Only 1% can also be identified as combining the use of their car with the BSS, having subscribed to a parking pass connected with the BSS. For the remaining 42% of Vélo’v members, we do not know if they own other transport passes. This fact is consistent with the findings concerning BSS users in Dublin (Murphy and Usher, Forthcoming).

The gender and age profiles of Vélo’v users do not display strong differences as compared to public transport users. With BSS, active members tend to correspond to young adults (under 14 year-olds are not allowed to rent bikes). The 18–24 and 25–34 age groups are over-represented: these two groups represent 60% of subscribers of the Vélo’v system even though they represent only 26% of the population of the “Grand Lyon” area, as can be seen on Table 2. The median age of active subscribers is 30.

A slight under-representation of women can be noted: annual Vélo’v members are more often male (56%) than female (44%). This fact is never reversed or neutralised: whatever the age of users, women are less likely to cycle than men. However, the difference gap varies: if the ratio is almost equal to one for the young users (20–24 years olds), it is greater for the users between 31 and 45 (especially 34–41 year-olds) as well as for teenagers (14–19 year-olds).

4.2. Temporal uses of Vélo’v: differences between annual members and short-term users

Existing works on the Vélo’v system in Lyon (Maizia and Dubedat, 2008; Jensen et al., 2010; Borgnat et al., 2011, 2013; Merchez and Rouquier, 2011; Ravalet and Bussière, 2012) do not consider any data on cyclists or Vélo’v users but, in part, draw



Map 2. Bicycle sharing system users in the “Grand Lyon” area.

Please cite this article in press as: Vogel, M., et al. From bicycle sharing system movements to users: a typology of Vélo’v cyclists in Lyon based on large-scale behavioural dataset. J. Transp. Geogr. (2014), http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005

Table 2
Comparison of Vélo'v users per age with public transport users (Grand Lyon/Kéolis, 2009).

Age	Number of active users	Percentage among active users	Percentage among TCL users	Percentage among the Grand Lyon population
5–17	1,353	2.7	20.1	18
18–24	14,616	28.9	21.2	11.1
25–34	15,733	31.1	16.9	14.9
35–49	11,983	23.7	17.7	22.1
50–64	5,978	11.8	14.6	20.8
65+	860	1.7	9.5	13.1

the main lines of temporal regularities in the use of BSS for the first years of the system's existence (2005–2007) on the basis of aggregated data on movements. Our dataset enables us to differentiate the temporal cycling patterns of usage of annual, weekly or daily members. We focus on differences amongst annual, weekly and daily rhythms.

The study of the system's pace over the year shows that BSS use is most intense in September, followed by April and May. August is the month when BSS use is least intense followed by December, January and February. There are however notable differences between members. Annual members have an overall regular use throughout the year (use increases by 50% between the month when they are minimal – i.e. August, with 300,000 trips – and the month when they are maximal – i.e. September with 460,000 trips). Short-term users (daily and weekly) have a much more seasonal use of the BSS: use reaches a low in January, and picks up most intensely from April to October and variations are more pronounced (uses increase by 80% between January – 90,000 trips – and September – 163,000).

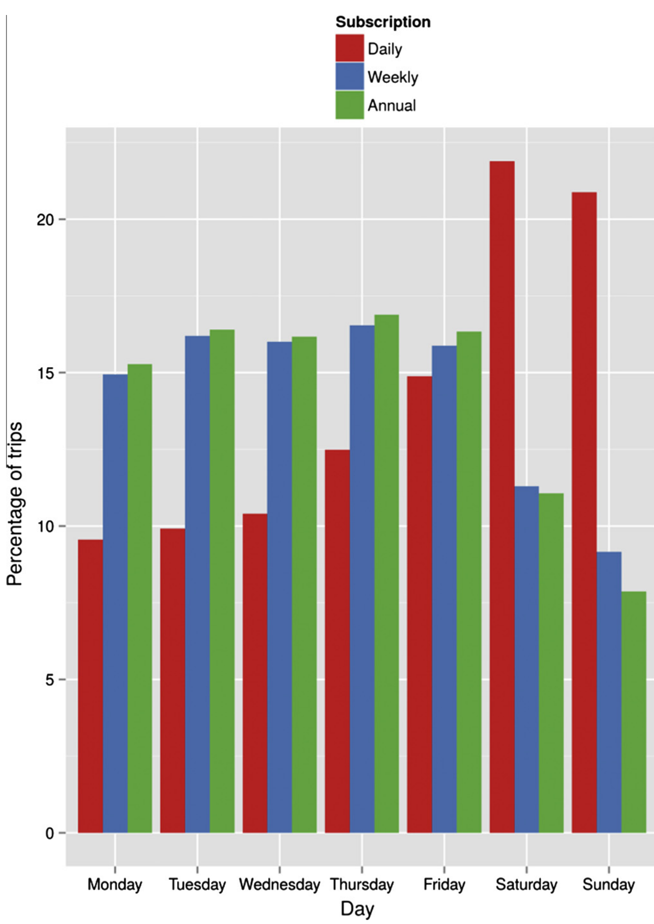


Fig. 1. Percentage of trips made by daily, weekly and annual subscribers according to the day of the week.

There is a striking difference in weekly use pattern between annual and weekly members on the one hand and daily users on the other (see Fig. 1). For annual members, weekly use is frequent and regular during the working week, reduced by a third on Saturdays and by around half on Sundays. The distribution is similar among weekly members. It is the opposite for daily pass holders: they mostly use the BSS at weekends.

Daily use highlights the social rhythms for annual and weekly members: the hourly distribution of trips reveals peaks at 8am and 6 pm, a stagnation at midday with an abrupt increase between 12 pm and 2 pm (see Fig. 2). Daily pass patterns follow a different trend: journeys are made mostly during the second half of the day and at night (i.e., when public transportation is no longer running).

Results show that the use pattern superimposes segmentation of types of users: annual or weekly commuter members contrast greatly with daily leisure members. The former make up 82% of all journeys (67.2% for annual, 14.8% for weekly members), the latter, 18%. The cycling patterns of annual members are not necessarily homogeneous in terms of intensity or regularity. On the contrary, daily members' cycling patterns are linked to leisure, including at night-time (after midnight, when public transport is no longer available). Such differentiation in cycling patterns according to membership types can also be seen in the average duration of trips: 13.5 min for annual members' trips, almost twice as much for daily passes' trips (22.8 min).

In order to characterise annual users more thoroughly, we put forward in the next section a typological reading of intensity and regularity patterns. It is not possible to do the same for short-term users, who by definition cannot be characterised in terms of regularity. However, it will be possible to re-introduce short-term users in the discussion of Section 6, even though they are not part of the analysis conducted in the following section.

5. Typology of annual members according to uses

Our choice is to build, through clustering methods, a typology of annual membership users, based on the cycling patterns distributed according to the intensity and the regularity of their practice.

5.1. Building a typology of users by clustering

A vector of attributes, called "profile", is described for each user, quantifying the intensity and regularity of his use over the week and throughout the year. For that, 21 attributes are defined, the first eight corresponding to weekly activity while the others correspond to annual activity, computed and normalised as follows:

- x_1^i: Averaged number of trips made per week, calculated over all the weeks during which user i travels at least once, and normalised dividing by 1.5 times the interquartile range of the distribution for all users (equal to the difference between the lower and upper quartile of the distribution).

Please cite this article in press as: Vogel, M., et al. From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset. J. Transp. Geogr. (2014), http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005

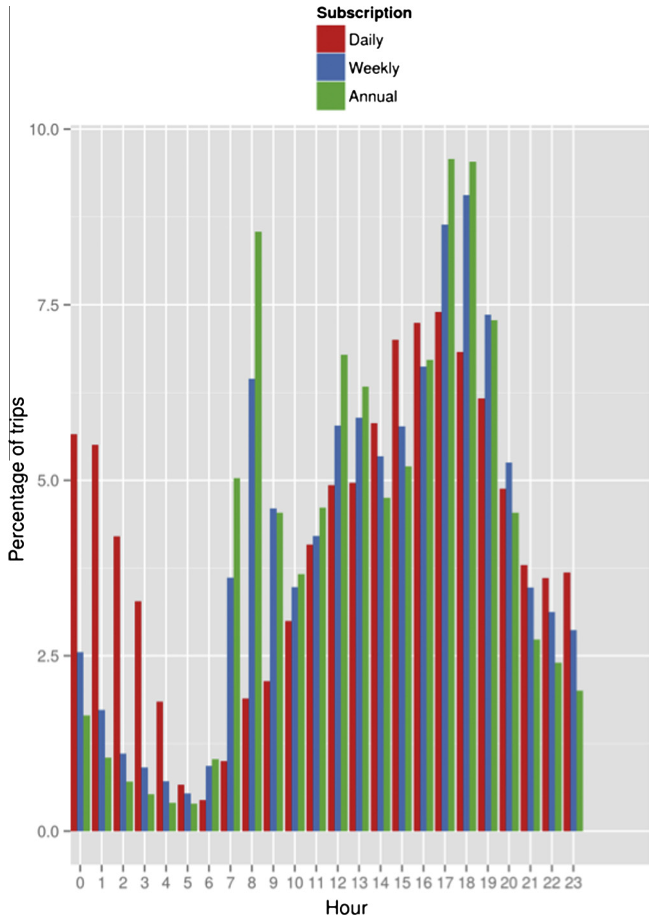


Fig. 2. Percentage of trips made with Vélo'v in 2011 by daily, weekly and annual users, distributed according to the departure time of the trip.

- $x_2^i, \ldots, x_6^i$: Average number of trips made on weekdays, sorted in increasing order; x_7^i: Average number of trips made on Saturdays; and x_8^i: Average number of trips made on Sundays. These seven features are normalised to a total sum unity over the week.
- x_9^i: Total number of trips made over the year, normalised dividing by 1.5 times its interquartile range of the distribution for all users:
- $x_{10}^i, \ldots, x_{21}^i$: Number of trips made for all months, sorted in increasing order and normalised to a total sum unity.

This adds up to the normalised profiles $X^i = (x_1^i, x_2^i, \ldots, x_{21}^i)$ for each user $i = 1, \ldots, n$. These profiles are visualised in the first factorial plan obtained by PCA on the X^i's (Fig. 3 bottom). The first two axes explain 85% of the total inertia of the data. Attributes 1 and 9 (intensity over the week and the year) are dominant for the first component while attributes 6 and 21 (percentage of movements on the busiest weekday and the busiest month) contributes with attribute 1 to the second axis. This informs us that there is some correlation between intensity and regularity attributes. Nevertheless, a simple *K*-means clustering method (see, e.g., (MacKay, 2003)) is used, coupled with statistical appraisal and careful analysis of the results, as our main intent is to create and interpret a relevant typology, not to find well-defined, pre-existing, classes. Also, we prefer to use the original variable directly instead of the PCA axes, because it makes the interpretation of the obtained classes straightforward.

Let us recall that, given an integer *K*, the *K*-means tries to minimise the within-cluster sum of squares S_k (Eq. (1a)) after grouping users in *K* clusters, or classes (noted C_k, with *k* from 1 to *K*, of centre μ_k):

$$\text{(a)} \quad \underset{\{C_1,\ldots,C_K\}}{\arg\min} \left(S_K = \sum_{k=1}^{K} \sum_{X^i \in C_k} \|X^i - \mu_k\|_2^2 \right)$$

$$\text{(b)} \quad \mu_k = \frac{1}{|C_k|} \sum_{X_i \in C_k} X^i \qquad (1)$$

The classical Lloyd algorithm obtains a solution by alternating assignment of each user to the cluster K_i having the nearest centre then adjusting the centres by computing Eq. (1b). To avoid keeping a sub-optimal solution, the algorithm is run with 10 random initial conditions and the best solution according to Eq. (1a) is retained (Peña et al., 1999).

The main issue is to agree on a relevant number of clusters *K*. Selecting this number always contains some arbitrariness. We next detail how we end up with a specific number of classes, combining a statistical criterion (based on Silhouette), preliminary analyses of partial profiles, and a study of the organisation of classes in which *K* is increasing. The Akaike Information Criterion (AIC) is not effective here because we do not have well defined classes, hence it would encompass a too broad scope of classes (more than 20).

A preliminary study is conducted using only partial profiles for each user. Using only the practice over the week (attributes 1–8) leads to a clustering in four classes differentiated by the intensity of use (high, medium and weak frequency) plus one with weak intensity that is concentrated on one specific day. Using only the profile for the year (attributes 9–21) outputs three clusters split according to their intensity of use. Combining the two classifications, one could expect twelve classes from the full profiles but it turns out that three of them are empty (e.g., a user cannot have an infrequent pattern over the week and a frequent pattern over the year). Therefore to study whether a typology in nine classes would make sense, we compute the score derived from the silhouette plot of the *K*-means (Rousseeuw, 1987), called the Average Means Silhouette (*AMS*), and computed as:

$$AMS = \frac{1}{n} \sum_{k=1}^{k} \sum_{X^i \in C_k} \left(\frac{\|X^i - \mu_{k_i'}\|_2 - \|X^i - \mu_k\|_2}{\max(\|X^i - \mu_{k_i'}\|_2, \|X^i - \mu_k\|_2)} \right) \qquad (2)$$

where k_i' is the number of the cluster closest to X^i different from the one C_k it is in. The larger the *AMS* is, the better the clustering is supposed to be. However, none of the two criteria points to a clear value of *K*. Looking at the *AMS* for *K* from 2 to 20, this score has a decreasing trend and this is expected because there are no clear-cut gaps between clusters but a continuous set of users. Since we aim to put forward a typology in more than two or three clusters (that are pointed out by the statistical criteria), we note that $K = 6$ or 10 appear as (locally) unadapted solutions for *AMS*, while 7, 12 and 16 are candidates for better clustering, with intermediate values in-between. For further analysis, we keep 3, 7, 9 and 12 as possibly relevant numbers of clusters, which have respective AMS values of 0.56, 0.42, 0.40 and 0.40 (per user).

To finally settle upon a relevant number of clusters, the partitions in three, seven, nine and twelve clusters are studied. A comparison between these possibilities is made by exploring the filiations of the clusters, i.e. what percentage of users in a cluster for a clustering with a given *K* (e.g., seven) were found in each cluster of the previous *K* (e.g., 3). This leads to the multi-clustering representation in Fig. 3 (top). On the bottom, the clusters are displayed colour-coded in the main factorial plan of *X*. Using only three clusters would reduce the typology to describe users with high, medium or weak frequency patterns only. We keep nine clusters for the interpretation of the typology because the clustering with seven or twelve classes is easily compared to the retained

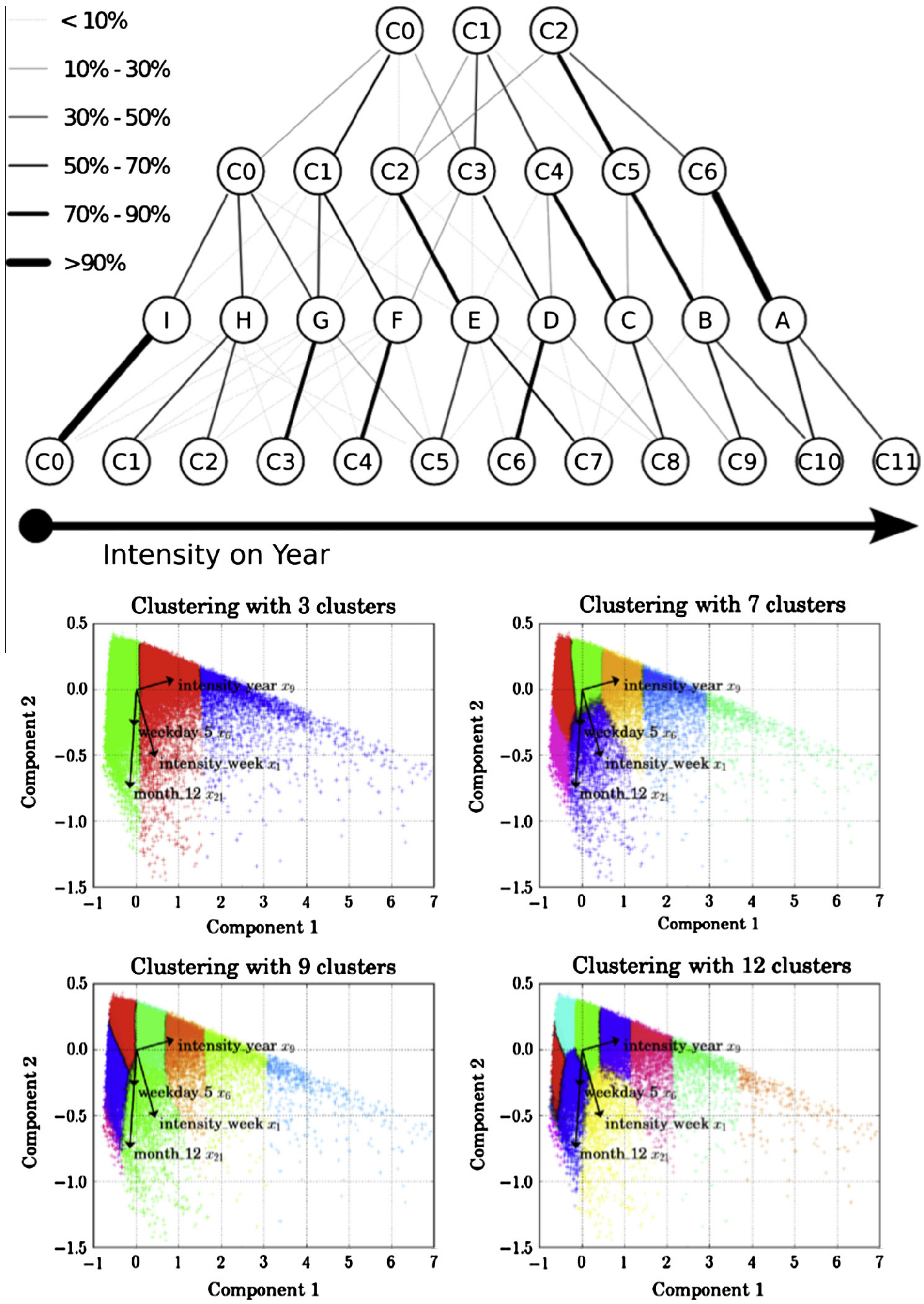


Fig. 3. Top: Hierarchical clustering with 3, 7, 9 and 12 clusters. Bottom: Plots in the main PCA factorial plan of the obtained clusters for clustering with the different numbers of clusters; each cluster is identified by a colour; the main explanatory attributes of the first two principal components are displayed.

one. On the one hand, having seven clusters would merge the users with weak frequency profiles in a sole cluster, with no subtlety to differentiate for instance concentrated use on specific days or instead spread out ones. On the other hand, going up to twelve classes would differentiate users active on Saturdays from users active on Sundays, yet the cost is the addition of two other classes providing no further insight into the users' profiles. The conclusion is that $K = 9$ is a sound number of classes, and this obtained typology will henceforth be analysed.

5.2. Analysis of the typology

The mean profiles of the nine clusters retained for analysis are given in Fig. 4. The clusters are sorted and named from class A (users having the most intensive usage) to class I (users with the least intensive usage). They are firstly differentiated by the intensity of use along the year with contrasted values (as seen in Fig. 4 (left) or in the main factorial plan in Fig. 3 (bottom)). For instance, classes A to D and F are fully differentiated by the intensity of use, each having a regular profile over the week (and more intense for working days) and balanced across many months along the year. These profiles are regular, as displayed in Fig. 4 (top right). On the contrary, class I describes users whose BSS pattern covers only one working day per week, while class H contains users specifically active at weekends only, with irregular profiles in Fig. 4 (bottom right). Finally, classes G and E figure group users with weak regularity over the year, crossed with low intensity for G (hence irregular users) and medium intensity for E.

Please cite this article in press as: Vogel, M., et al. From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset. J. Transp. Geogr. (2014), http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005

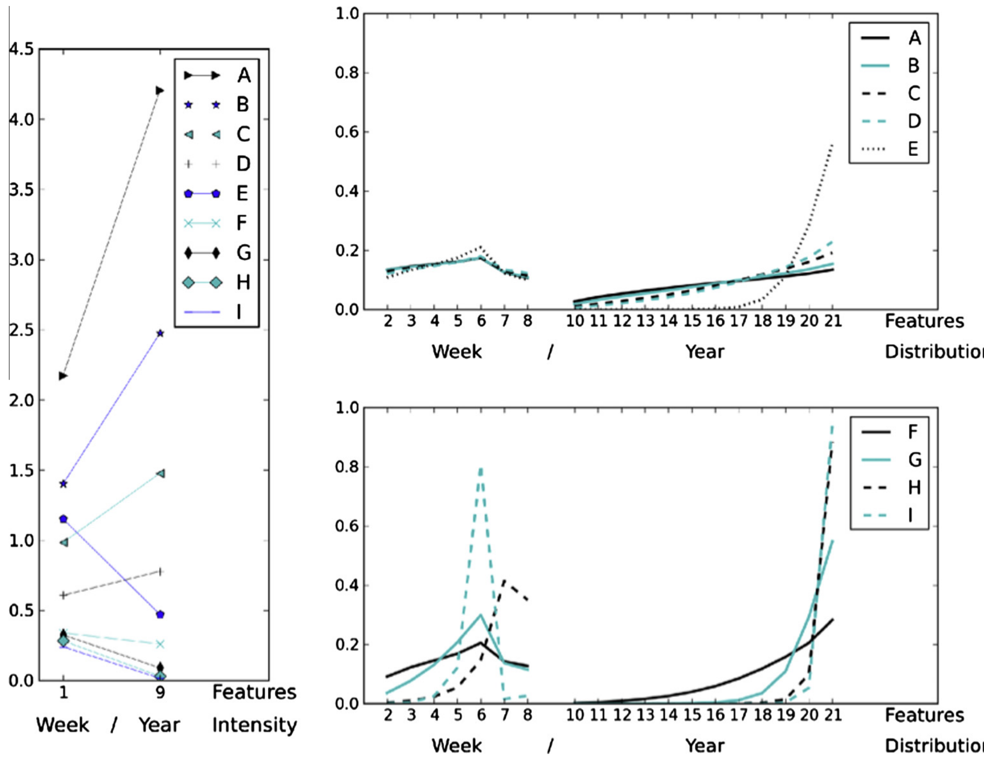


Fig. 4. Averaged profiles for the 9 classes. Left: Attributes 1 and 9 describe intensity over the week and over the year. Right: Attributes 2–8 quantify the normalised profile of regularity of BSS use over the week (1 attribute per day), and Attributes 10–21 along the year (1 attribute per month). The plot is separated in two, one with clusters A to D that display a regular profile over the week and year (except E) and clusters F to I for which only F has a regular profile (and only over the week).

Table 3
Various features that characterise, with hindsight, the nine classes of users, compared to the same features for the totality of the long-term users in 2011.

Class of users	Number of users	Average number of trips per user	Average number of active month per user	Gender ratio W/M	Median age	Total number of movements	Distribution of women (%)	Distribution of men (%)
A – extreme users	526 (1%)	693.8	11.4	0.25	31	364,965 (8.4%)	0.47	1.49
B – very intensive and frequent	2029 (4%)	408.1	11.1	0.38	28	828,018 (19.0%)	2.53	5.19
C – intensive and regular	4288 (8%)	243.8	10.3	0.55	28	1,045,328 (24.0%)	6.80	9.83
D – quite intensive and regular	7925 (16%)	128.3	9.8	0.66	31	1,017,166 (23.3%)	14.2	16.9
E – intensive and part-time	2790 (6%)	77.7	3.3	0.61	24	216,830 (5.0%)	4.76	6.13
F – moderate and quite regular	16,250 (32%)	43.1	7.9	0.82	30	699,701 (16.0%)	32.8	31.7
G – irregular	11,509 (23%)	14.9	3.3	1.03	30	171,121 (3.9%)	26.3	20.0
H – "Sunday cyclists"	2586 (5%)	5.1	1.5	1.12	32	13,210 (0.3%)	6.15	4.31
I – "one-off" users	2577 (5%)	2.8	1.2	1.08	36	7162 (0.2%)	6.01	4.39
Total	50,480 (100.0%)	86.44	6.6	0.79	30	4,363,501 (100%)	100	100

To complete the description from normalised features, Table 3 presents the main characteristics of the nine classes. Firstly, the contrast in the number of trips per year still appears clearly. From two trips per year to more than 690 per year, the contrast is sharp, and classes of active users are never quantitatively negligible. The top four classes (29% of active users) are responsible for almost 75% of the journeys. The bottom two classes, H and I, which comprise almost ten times more users than class A, are responsible for less than a tenth of the trips made by users of class A; they correspond to users who hardly ever use their subscription (class I) or sporadically at weekends only (class H).

Secondly, the distribution of the average number of trips over time ranges from a "one-way and one time" use of the annual subscription to everyday use. Far from a differentiation with reference to the sole variable of intensity of use, the typology highlights classes of highly intensive use concentrated on a small part of the year (see class E), which would not be visible if we consider only data on the number of trips per year. To compute the number of active months in Table 3, a user has activity during a month if he makes at least one trip. Based on these contrasting features, a label to refer to each class is proposed in the following section, developing an interpretation of the classes of users and a closer discussion of

Please cite this article in press as: Vogel, M., et al. From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset. J. Transp. Geogr. (2014), http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005

the typology, with regards to the conclusions of the previous sections.

6. Discussion

Although the clustering method exhibits nine classes of users, it is fairly easy to interpret them into four categories, for which the contrast is then strong. Using different variables such as gender, age and postcode, and other variables concerning use, a closer description of four groups of users can be made. Also, nine classes of users with annual membership cards are exhibited by the clustering method and one objective is to compare their different habits in the use of Vélo'v. Also, by considering the characteristics of short-term (daily and weekly) users described in Section 4, it will be possible to integrate these short-term users in a general discussion about Vélo'v users, although the latter users are not part of the clustering.

In order to do so, it is necessary to comment and interpret first the clusters as four categories that show a strong contrast between them. The first classes A and B present a high similarity (very high intensity and regularity), and so do classes G and H for opposite reasons (very low intensity and regularity). Likewise, the user profile of class E can be closer to classes C (intensive use but only on a fraction of the year) and D. The density of use (number of active weeks during the time lapse of use) is high in class E and low in class G.

(1) "User of heart": users from classes A and B show a very intensive use of the BSS with a high regularity over the year and over the week. We do not know whether or not they own a car and have a strong cyclist conviction as in Jensen's typology (1999) but they seem to use almost exclusively or at least mostly the Vélo'v system as a means of transport. In any case, with an average of 466 journeys a year, these cyclists ride in all kinds of weather and are physically invested in cycling. They represent less than 5% of all members and they compose around 27.4% of all trips in 2011. This category is clearly male-dominated (73% of users are male) and the median age is slightly higher (31 year old) for the more active part of the category compared to others categories.

(2) "Assiduous users": this category gathers intensive and regular users from classes C and D (close to 30% of users). Class E is added to this group, as the users are as intensive as users in C (23 trips per month). However, they show less than four months of activity on average. These users have a settled use of the system during the year (from 128 journeys per year for users from cluster D to 243 journeys per year for those from class C) or during a shorter period (around one quarter for users from class E). This category is also male-dominated (the female/male ratio is around 0.6) and gathers two age groups, the first with a median age of 30 and the second, younger, with a median age around 24, mainly belonging to class E. A hypothesis to explain the brevity of their uses over the year is that these users are, for a large part, students or trainees, living in Lyon during a short period in 2011 (47% of them make their first journey during the last term of the year).

(3) "Multimodal users": these users are the ones found in class F. The intensity of their use of the Vélo'v is low but regular over the year (on average, 43 journeys per year distributed over 8 months). As 32% of subscribers belong to this category, it is the category of the standard users. The gender ratio is better balanced (0.82) than that of the two previous categories. The category is well balanced as it includes 31% of all male users and 32% of all female users. The median age is 31. The hypothesis about these users is that they use the Vélo'v system as a means of transport among all the possibilities offered in the city.

(4) "Sporadic users": mostly composed of users from class G (low intensity for 3 months relatively spread over a year), this category also comprises class H (little activity, mainly on weekends) and class I where users are almost "one-off" users (1 or 2 journeys only during the year). This category counts 16,600 users (33% of the total) who are most often women (the gender ratio is equal to 1.05). The low cost of annual memberships mainly explains the large size of the category.

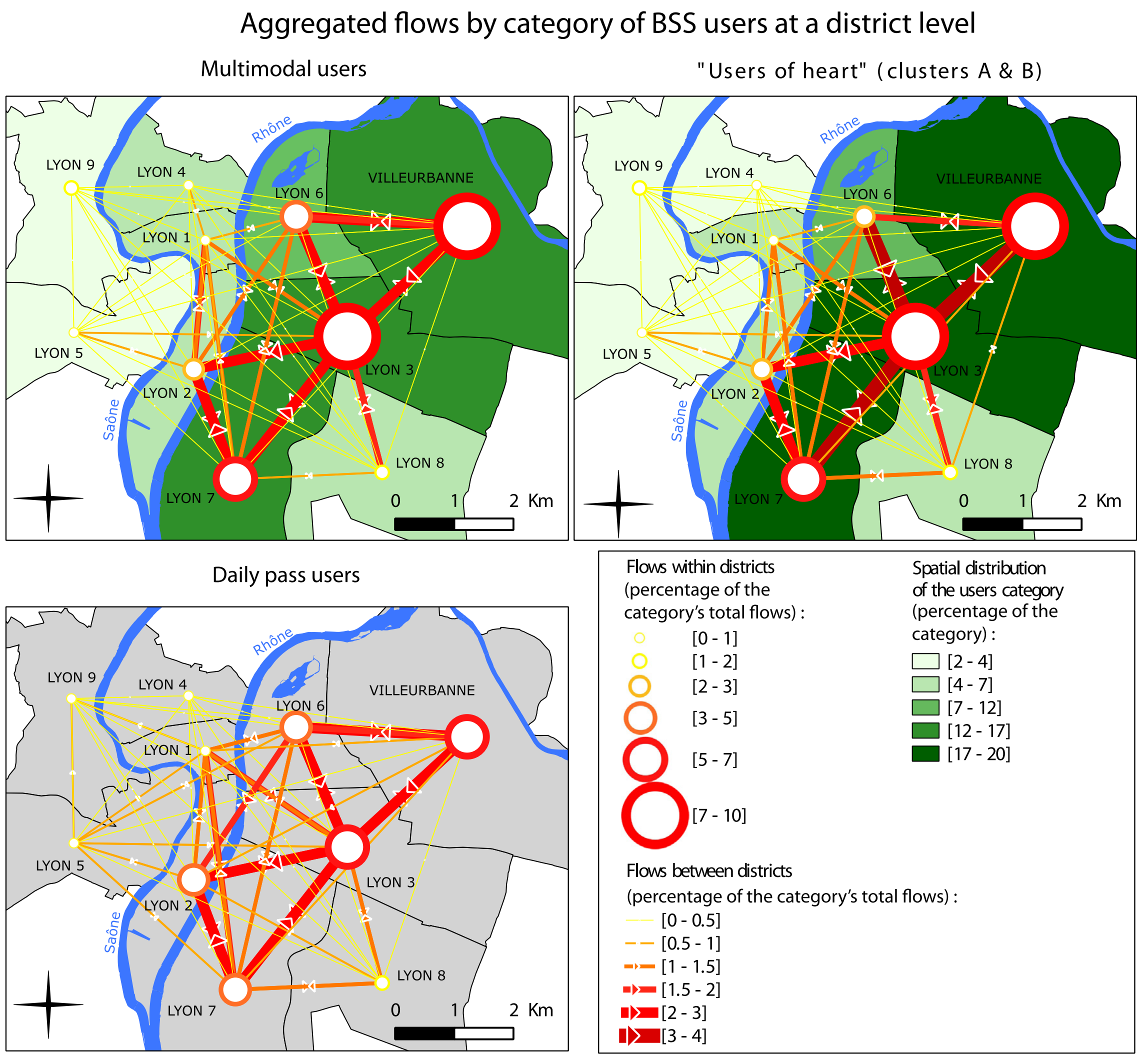
We can now add to the typology of annual members, the category of weekly and daily members, and the analysis that was conducted in Section 4, and draw the conclusion that there is a partial overlap of practices and differences. Weekly members can be related to "sporadic users" from cluster G, while daily members have a specific type of practice (at weekends and at night-time) which may allow us to add a fifth group whose practice is more clearly marked by leisure on the one hand (as H) and by a specific function of the BSS on the other (available at night when public transportation is unavailable). The latter group (the fifth group) could correspond to relatively frequent users of the "daily pass".

This typology in four or five categories recalls, in broad outline, those presented by different authors about ordinary or BSS cyclist typologies (Jensen, 1999; Pucher and Buehler, 2012; Dill and McNeil, 2013; Sener et al., 2009; Buck et al., 2012) in which the intensity and range of the cycling practice over the year highlights fairly different audiences. It reintegrates BSS into the larger group of ordinary cyclists, while also showing areas of difference. Also, the results liken BSS to a public transportation that can be used independently or in a multimodal manner. It also emphasises the necessity to consider it as a component of interdependent transport systems.

The categories are distinctly gendered. The intensity of practice is strongly linked to masculinity: the first two categories are clearly male while the "middle-class" of multimodal users is far less so. Finally, there is no proven difference in terms of age between categories – except for two sub-groups: class E, notably younger than average (24), and class I being older (36).

These observations – users are more often young and male and so are the intensive users – are consistent with those made more broadly on cycling in France (Héran, 2012; CERTU, 2013), though less pronounced in the case of BSS users. The CERTU study in Strasbourg – where the modal share of cycling amounts to 7.6%, i.e. twice as much as in other French cities, and age and gender differences are reduced – confirms what has been observed elsewhere (Bonham and Wilson, 2012; Beecham and Wood, 2013; Martens, 2013). The increase of the modal share of cycling generally goes along with a decrease in age and gender gaps. The typology allows us to qualify our point about gender differences and to take a more precise approach: the class "Multimodal users" is a well-balanced pivotal group, which would have gone unnoticed by looking only at averages.

What can be said about the spatial distribution of each category of users? It is interesting to note that the residence location is not a relevant parameter to distinguish clusters or categories. There is no over-representation of one or several clusters in one or another district, which means that the use of a Vélo'v is not strongly related to the user's postcode. We can however temper this comment. The highly intensive users ("Users at heart" and "Assiduous users") are relatively more numerous in well-connected districts (2nd, 3rd, 6th, 7th districts of Lyon and Villeurbanne) and conversely. Nonetheless, it could be argued



Map 3. Aggregated flows by category of BSS users at a district level.

that districts are too wide in terms of spatial units to allow a close reading of the spatial distribution.

Spatial practices do not distinguish classes or categories of users, either. If we focus on aggregated flows by category of BSS users at a district level (within or between districts), there are not many differences (see Map 3). "Users of heart" and "Multimodal users" have a similar use of the BSS, in the downtown area as well as for intra-district journeys. On the contrary, spatial practices of one-day pass holders appeared to be more homogeneous/constant in terms of movements both within and between districts. The distribution of individual mobilities (which are recognisable thanks to the indicator of "spatial density of use" – the ratio between the number of journeys to and from the four most used stations and the total number of journeys) is also relatively low and with little variation between categories (the average being between 0.6 and 0.7).

Such regularity underlines, across all categories, the proximity to the place of residence (within districts), in connection with transport (railway and underground stations), employment, services and leisure areas that are concentrated in Lyon in the same urban limits. Seen in this way, Lyon contrasts sharply with London, where spatial specialisation (discrepancies between residential and employment areas) is more pronounced and BSS journeys are often combined with railway use (Beecham and Wood, 2013).

Limitations of the study

There are two kinds of limitations to this study. The first kind stems from the corpus: we only had access to demographic data concerning annual members, accounting for over 67% of movements in total. Information concerning the regularity or intensity of daily and weekly members remains unknown in the corpus. The second limitation is related to the approach. Segmenting the population of users only on the basis of their effective cycling patterns offers a precise and precious vision of the BSS users – yet also a limited one as this work does not include the incentives of choice and the preferences of users. However, this is the first step to a broader research program still in progress, also including surveys and interviews with users and non-users of the BSS.

7. Conclusion

By accessing exhaustive bicycle movement and user databases, instead of the more classical declarative surveys, we have sought to present a clustering method which stems from the profiles of intensity and regularity of uses of each member. This typology sheds light to actual usages of BSS users. Further, changing the focus from bicycles to users enabled us to put forward a typology comprising a wide range of user types, from "user of heart" to

Please cite this article in press as: Vogel, M., et al. From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset. J. Transp. Geogr. (2014), http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005

"sporadic users". We claim/conclude that this organisation echoes classical typologies of ordinary (non BSS) cyclists.

The first relevance of the proposed typology is descriptive. It allows us to discriminate four groups of users with strongly pronounced features. It shows for instance a gender-related modulation. However, the typology shows no significant differences in spatial uses, which turns out to be consistent with the spatial overlap between residential, professional and leisure activity areas of BSS users. Further analysing spatial uses would require a more detailed consideration of the spatial features associated with BSS main users. Nevertheless, this typology revealed that the numerically dominant category of users, which can be considered as a "middle-class" of BSS users, is well-balanced in terms of gender compared to the other ones.

The typology has a second, interpretative relevance. Following previous works (Jensen, 1999; Martens, 2013), a possible hypothesis is that the characteristics of a practice of cycling considerably determine the perception of this activity (in terms of safety, of modal choice, of sharing the street). This was successfully demonstrated for instance in (Murphy and Usher, Forthcoming) concerning biking and car driver awareness. Having a clustering of practice-based users is a sound complement to analyses usually made according to standard sociological features (gender, age and income). These groups of users defined by their practice could thus constitute target audiences for pro-cycling strategies, enforced by both the metropolis and the operator.

The present study constitutes the first phase of a broader research program which intends to explore more thoroughly the practice of BSS. It will no longer rely solely on intensity and regularity of the practice over the year but also on more targeted modalities such as the spatial distribution of movements or frequencies of movements at different time scales. Specific surveys and interviews of Vélo'v users will complete it. One purpose of the developed typology of BSS cyclists is to contribute to the comparison of active (walking, cycling, or with BSS, or with cars) and non-active (with public transport) urban mobilities, in the context of new multimodal movement patterns. We intend to follow up on this article by comparing the Lyon BSS with BSS established in Valencia (Spain) and in Montreal (Canada). This comparison should enable us to highlight commonalities between BSS users and usages, such as the weight of local socio-historical parametres which preform them.

Acknowledgements

The authors acknowledge support of the ANR-12-SOIN-0001-02 grant and thank JCDecaux and Grand Lyon for access to the data.

References

Authier, J.-Y., Grafmeyer, Y., Mallon, I., Vogel, M., 2010. Sociologie de Lyon, Paris, La Découverte.

Bachand-Marleau, J., Lee, B.H., El-Geneidy, A.M., 2012. Better understanding of factors influencing likelihood of using shared bicycle systems and frequency of use. J. Transport. Res. Board 2314, 66–71.

Beecham, R., Wood, J., 2013. Exploring gendered cycling behaviours within a large-scale behavioural data-set. Transport. Plan. Technol. 37 (1), 83–97.

Bergstrom, A., Magnusson, R., 2010. Potential of transferring car trips to bicycle during winter. Transport. Res. Part A: Policy Practice 37 (8), 649–666, 2003.

Bonham, J., Wilson, A., 2012. Bicycling and the life course: the start-stop-start experiences of women cycling. Int. J. Sustain. Transport. 6 (4), 195–213.

Borgnat, P., Abry, P., Flandrin, P., Robardet, C., Rouquier, J.-B., Fleury, E., 2011. Shared bicycles in a city: a signal processing and data analysis perspective. Adv. Complex Syst. 14 (03), 415–438.

Borgnat, P., Robardet, C., Abry, P., Flandrin, P., Rouquier, J.-B., Tremblay, N., 2013. A dynamical network view of Lyon's Vélo'v shared bicycle system. In: Dynamics on and of Complex Networks. Springer, New York, pp. 267–284.

Buck, D., Buehler, R., Happ, P., Bradley R., Chung, P., Borecki, N., 2012. Are bikeshare users different from regular cyclists? A first look at short-term users, annual members, and area cyclists in the Washington DC. In: 92th Annual Meeting of the TRB, Washington DC.

CERTU, 2013, Usagers et déplacements à vélo en milieu urbain. Analyse des enquêtes ménages déplacements. Lyon, 59p. <http://www.certu-catalogue.fr/usagers-et-deplacements-a-velo-en-milieu-urbain.html>.

Christmas, S., Helman, S., Newman, C., Hutchins, R., 2010. Cycling, Safety, and Sharing the Road: Qualitative Research with Cyclists and Other Road Users. Department for Transport, London, United Kingdom.

Damant-Sirois, G., Grimsrud, M., El-Geneidy A.M., 2013. What's your type: a multidimensional cyclist typology. In: 93rd Annual Meeting TRB, Washington DC.

Dill, J., McNeil, N., 2013. Four types of cyclists? Examining a typology to better understand bicycling behavior and potential. In: 93rd Annual Meeting of the TRB, Washington DC.

Fishman, E., Washington, S., Haworth, N., 2013. Bike share: a synthesis of the literature. Transport Rev. 33 (2), 148–165.

Fuller, D., Gauvin, L., Kestens, Y., Daniel, M., Fournier, M., Morency, P., Drouin, L., 2011. Use of a new public bicycle share program in Montreal, Canada. Am. J. Prev. Med. 41 (1), 80–83.

Grand Lyon, Direction Prospective et Stratégie d'Agglomération (DPSA), 2006. Vélo'v, une nouvelle offre de service pour favoriser l'usage du vélo en ville, mai. 30p.

Grand Lyon, Kéolis, 2009, Enquête usages et profils.

Heinen, E., van Wee, B., Maat, K., 2010. Commuting by bicycle: an overview of the literature. Transport Rev.: Trans. Transdisciplinary J. 30 (1), 59–96.

Héran, F., 2012.Vélo et politique globale de déplacements durables, Rapport du Prédit, Lille, Clersé.

ITDP, 2013. Institute for Transportation and Development Policy. <https://go.itdp.org/display/public/live/The+Bike-Share+Planning+Guide>.

Jensen, M., 1999. Passion and heart in transport – a sociological analysis on transport behaviour. Transp. Policy 6, 19–33.

Jensen, P., Rouquier, J.B., Ovtracht, N., Robardet, C., 2010. Characterizing the speed and path of shared bicycle use in Lyon. Transport. Res. Part D: Transport Environ. 15 (8), 522–524.

Lathia, N., Ahmed, S., Capra, L., 2013. Measuring the impact of opening the London shared bicycle scheme to casual users. Transport. Res. C 22, 88–102.

MacKay, D., 2003. Information Theory, Inference, and Learning Algorithms. Cambridge University Press.

Maizia, M., Dubedat, É., 2008. Analyse quantitative d'un service de vélos en libre-service: un système de transport à part entière. Flux 1, 73–77.

Martens, K., 2013. The role of bicycle in limiting transport poverty in Netherlands. Transport. Res. Rec.: J. Transport. Res. Board 2387, 20–25.

Merchez L., Rouquier J.-B., 2011. Les rythmes urbains au prisme du Vélo'v. Données urbaines, 6, Mattéi M.-F. and Pumain D. (dir.), Paris, Anthropos, pp. 93–104.

Midgley, P., 2011. Bicycle-sharing Schemes: Enhancing Sustainable Mobility in Urban Areas. New York: United Nations. <http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background-Paper8-P.Midgley-Bicycle.pdf>.

Morency, C., Trépanier, M., Godefroy, F., 2011. Insight into Montreal's bikesharing system. In: 90th Annual Meeting of the TRB, Washington, DC.

Murphy, E., Usher, J., Forthcoming. The role of bicycle-sharing in the city: analysis of the Irish experience. Int. J. Sustain. Transport. http://dx.doi.org/10.1080/15568318.2012.748855.

Nair, R., Miller-Hooks, E., Hampshire, R.C., Bušić, A., 2013. Large-scale vehicle sharing systems: analysis of Vélib'. Int. J. Sustain. Transport. 7 (1), 85–106.

O'Brien, O., Cheshire, J., Batty, M., 2014. Mining bicycle sharing data for generating insights into sustainable transport systems. J. Transp. Geogr. 34, 262–273.

Ogilvie, F., Goodman, A., 2012. Inequities in usage of a public bicycle sharing scheme: socio-demographic predictors of uptake and usage of the London (UK) cycle hire scheme. Prev. Med. 55 (1), 40–45.

Papon, F., 2012. Analysis of data sources on bicycle mobility. international workshop: spatio-temporal data mining for a better understanding of people mobility. In: The Bicycle Sharing System (BSS) case study, Ifsttar. <http://hal.archives-ouvertes.fr/hal-00851297>.

Peña, J.M., Lozano, J.A., Larrañaga, P., 1999. An empirical comparison of four initialization methods for the K-means algorithm. Pattern Recogn. Lett. 20 (10), 1027–1040.

Pucher, J., Buehler, R. (Eds.), 2012. City Cycling. MIT Press, Cambridge.

Ravalet, E., Bussière, Y., 2012. Les systèmes de vélos en libre-service expliquent-ils le retour du vélo en ville ? Recherche Transports Sécurité 28 (1), 15–24.

Rousseeuw, P.J., 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. Comput. Appl. Math. 20, 53–65.

Sener, I.N., Eluru, N., Bhat, C.R., 2009. An analysis of bicyclists and bicycling characteristics: who, why, and how much are they bicycling? In: 89th Annual Meeting of the TRB, Washington DC.

Shaheen, S., Guzman, S., Zhang, H., 2010. Bikesharing in Europe, the Americas, and Asia. Transport. Res. Rec.: J. Transport. Res. Board 2143, 159–167.

Shaheen, S., Zhang, H., Martin, E., Guzman, S., 2011. Hangzhou public bicycle: understanding early adoption and behavioural response to bike sharing in Hangzhou, China. In: 91th Annual Meeting of the TRB, Washington DC.

Shaheen, S., Martin, E., Cohen, A.P., Finson, R., 2012. Public Bikesharing in North America: Early Operator and User Understanding. Mineta Transportation Institute, San Jose, CA.

Please cite this article in press as: Vogel, M., et al. From bicycle sharing system movements to users: a typology of Vélo'v cyclists in Lyon based on large-scale behavioural dataset. J. Transp. Geogr. (2014), http://dx.doi.org/10.1016/j.jtrangeo.2014.07.005