Promoting sustainable mobility by modelling bike sharing usage in Lyon

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Abstract. This paper aims to present a modelling of bike sharing demand at station level in the city of Lyon. Multiple linear regression models were used in order to predict the daily flows of each station. The data used in this project consists of over 6 million bike sharing trips recorded in 2011. The built environment variables used in the model are determined in a buffer zone of 300 meters around each bike sharing station. The results show that bike sharing is principally used for commuting purposes. An interesting finding is that the bike sharing network characteristics are important parameters to improve the prediction quality of the models. The present results could be useful for others cities which want to adopt a bike sharing system and also for a better planning and operation of existing systems. The approach in this paper can be useful for estimating car-sharing demand.

1. Introduction
During the last decade, bike sharing systems become more and more popular in the world. In the end of 2014, the bike sharing scheme is present in more than 50 countries with more than 700 systems and about 700,000 bikes (Larson et al. 2014). Bike sharing is considered as an alternative and complementary mode of transportation which has traffic and health benefits such as flexible mobility, physical activity benefits and supports for multimodal transport connections (Shaheen et al. 2010). Bike sharing can provide an alternative to traditional modes of transport or a complementary service for solving the “last mile problem” of getting from a public transportation stop to the final destination. In France, the bike sharing system is implemented in more than 35 cities in order to improve soft mode transportation and encourage the sustainable development. Vélo’v, the bike sharing system of the Metropole of Lyon, installed in May 2005 and operated by JC Decaux, is recognized as a success of bike sharing. In 2014, Vélo’v has 348 stations and more than 4,000 bicycles with about 58,000 long-term subscribers in 2014 for an average of 23,000 rentals per day (Lyon Capitale 2014). Although bike sharing is becoming popular in France and around the world, there are relatively few quantitative studies exploring the influence of built environment on the bike sharing usage. To ensure the success of bike sharing schemes, it is important to understand the influence of built environment on the bike sharing usage. Vélo’v in Lyon city is mature and successful bike sharing system that offers a unique opportunity for understanding the factors influencing on bike sharing usage. In this paper, we
use bike sharing trips data of Vélo’v in 2011 and built-environment parameters to estimate the bike sharing’s daily flow during a weekday at station level.

2. Literature review

Four generations of bike sharing have been introduced since the first bike sharing system in the 1960s in the Netherlands (De Maio et al. 2009; Shaheen et al. 2010). Bike sharing has become more popular since the introduction of the 3rd generation, with the automatic transaction kiosk at each station and identified bike sharing users. These bike sharing systems of the 3rd generation are relatively successful around the world. Currently, the majority of bike sharing systems are of the 3rd generation; there are some bike sharing systems of the fourth generation installed in Copenhagen and Madrid with improving docking stations, bike redistribution, integration with other transport modes (De Maio et al. 2009; Shaheen et al. 2010) and electrical bikes. In the Metropole of Lyon, the bike sharing system, called Vélo’v, belongs to the 3rd generation of bike sharing systems. Vélo’v bike sharing system is installed in the city of Lyon and Villeurbanne which cover an area of 60 kilometer square for more than 647 000 inhabitants (2013). The Vélo’v system aggregated more than 6.2 million trips in the 2011 and 8.3 million bike sharing trips recorded (Tran et al. 2014; Lyon Capitale 2014).

In recent years, many researches have used traditional surveys in order to determine the factors that may promote the adoptions of bike sharing by urban populations (LDA Consulting 2013; Melbourne BSS survey 2015). The automated data collected from docking stations constitutes a precious source of information to better understand the usage of bike sharing in the city. There have been several studies conducted using data from the Vélo’v system. These studies use bike sharing flow data obtained from stations to determine the typology of bike sharing users or to analyze the characteristics of bike sharing usage. They contribute to the literature by studying user behavior in response to bike sharing system and examining the characteristics of this system. Regarding the Vélo’v system, the average speed of bike sharing is 14 km per hour (Jensen et al. 2010) and the average duration of bike sharing trip is about 15 minutes. There are also several researches that determine a typology of bike sharing stations using the real bike sharing data trips (Froehlich et al. 2009; Lathia et al. 2012; Kaltenbrunner et al. 2010). They have determined that there are different groups of bike sharing stations according to their operation during a working day. The current paper contributes to literature by modelling the daily bike sharing demand at station level using the socio-economic parameters determined in a buffer zone around bike sharing stations using multiple linear regression models.

3. Mobility and bike sharing in the metropole of Lyon

The Metropole of Lyon is the second biggest agglomeration in France after Grand Paris with 1 324 637 inhabitants (2012) on a surface of 533.7 km square. The major public transport system (metro and tram line) of Lyon is mainly installed in the city of Lyon and Villeurbanne on a surface of 62.47 km square. There are 4 lines of metro, 2 funiculars and 5 tram lines. The surface public transportation is composed by 5 tram lines. The shift modal of bicycle in Lyon city is about 1.7% in 2006 according to the Household Travel Survey. The population of Lyon and Villeurbanne are relatively concentrated in the city center (see figure 1) while the employment density is important in the city center and some others zones far from the center (see figure 2).
Figure 1. Bike sharing station and the population density by grill in the city of Lyon and Villeurbanne, source: JC Decaux, INSEE.
Figure 2. Bike sharing station and the employment density by IRIS zone in the city of Lyon and Villeurbanne, source: JC Decaux, INSEE.

The bike sharing system of the Metropole of Lyon, operated by JC Decaux, was installed in the city of Lyon and Villeurbanne, in May 2005 with 173 stations and 2 000 bikes. In 2014, this system has 348 stations and 4 000 bikes with more than 8 million trips. Bike sharing user can choose between three types of subscription: annual, weekly or daily with a minor cost equal to 25 euros, 5 euros or 1.5 euros respectively to be paid by a credit card. Bike can be rented from 0h to 24h and 7 days a week. The first 30 minutes is free for all subscribers; after the first free half hour users pay € 0.75 for every subsequent half hour, for a maximum of one hour. If the one hours limit is exceeded, the user is charged 1.75 euros per half hour. A 150 euros penalty is charged if the bike is not returned within 24 hours of its withdrawal from the station. The average number of daily trips is about 23 000 trips per day in 2014. By analyzing the data of bike sharing trips in 2011, we found that the level of bike sharing usage is not uniformly distributed during the days of week during the months of year: bike sharing is mostly used during working days and the usage level decreases considerably in vacation months (July, August) and in winter months. The difference of bike sharing usage by day and by month justifies our choice of bike sharing flows for modelling (see figure 3).
4. Data
The main objective of the study is to estimate the daily flows of bike sharing using the various socio-economic factors determined at station level. The data used in this study consists of all bike sharing trips in 2011: over 6 million trips and the built environment data geo-computed by the GIS-transport modelling platform MOSART developed by the researchers from Transport, Urban Planning and Economics Laboratory. Firstly, we are going to explain the processes of determination of bike sharing flows and socio-economic variables. Secondly, the multiple linear regression models are going to presented and used to estimate the daily flows of bike sharing.

4.1 Bike sharing trips data
In this study, we used the bike sharing trips data obtained from JC Decaux – operator of Lyon bike sharing system, for all stations during the year of 2011. Each trip gives us information about the departure and arrival stations, the date and hour of check in and check out and the type of subscribers. In order to calculate the flows of bike sharing, we aggregated the bike sharing trips per hour. All non-valid trips were eliminated. A non-valid trip is a trip less than 3 minutes or more than 2 hours. The data aggregated were calculated only for working days (from Monday to Friday and not during school holidays and public holidays). We eliminated also the bike sharing trips made during July and August because they are the months of vacations in France. Finally, 178 working days were counted for calculating bike sharing flows in 2011. We eliminated from our analysis 6 stations that were partially or totally inactive in 2011; 10 stations were combined to 5 couples of stations because they are situated very close to each other’s. Finally, there are 331 bike sharing stations in our study.

![Figure 3. Average daily bike sharing trips per station by day (on the left) and by month (on the right) in 2011, source: using data from JC Decaux.](image)

| Table 1. Descriptive on the daily usage of bike sharing per station in Lyon |
|-----------------------------|--------|-------|-------|--------|
|                            | Sample | Minimum | Maximum | Average | Std. Deviation |
| Daily inbound flow         | 331    | 2       | 383     | 59      | 50             |
| Daily outbound flow        | 331    | 1       | 345     | 57      | 46             |

4.2 Built environment variables
In order to analyze the influence of built environment on bike sharing usage, we determined built environment variables around each station. The explicative variables used in our analysis can be categorized in five groups: public transport variable, socio-economic variable, topographic variable, bike sharing network variable and leisure variable. Different sizes for a buffer zone were tested: 200m buffer zone, 300m buffer zone and 400m buffer zone. A 300 meter buffer zone was chosen because the explanatory variables determined within a 300m buffer zone are statistically most correlated to the bike sharing flows and it was to found to be an appropriate walking distance between Vélo’v stations according to the results of bike sharing survey of Lyon in 2007. In terms of public transit variables, the number daily passengers of metro and tramway; and railway stations near a Vélo’v station were
generated to examine the influence of public transit on bike sharing flows. The variables of public transit were normalized by the number of passengers of each station per day.

The socio-economic variables included 3 factors: population between 18 and 64 years old, number of jobs and average income in the buffer zone of a bike sharing station. The elevation of each station was calculated to examine the influence of topographic variable on bike sharing usage. The length of bicycle facilities in the buffer zone was also calculated to capture the impact of placing Vélo’v stations near bicycle facilities on the usage of the bike sharing system. Leisure variables are also considered in our analysis: number of restaurants, number of cinema, and number of night clubs; the presence of a park and the presence of Embankment Road in the buffer zone of a bike sharing station. In terms of public transit system, there are 2 variables considered: the number of daily passengers of metro and tramway; and the number of daily passengers of railway station.

The number of bike sharing stations in a 3,500 meter buffer zone, the number of bike sharing stations in a 300-meter buffer zone around a Vélo’v station and the capacity of each Vélo’v station were computed to capture the effect of bike sharing network on the daily usage. The 3,500 meter buffer zone which covers about 95% bike sharing trips represents the opportunity of findings a bike sharing station of an user when he want to make a trip. The 3 variables of bike sharing network were added a posteriori of our modelling in order to improve the predictive quality. Finally, there are 15 socio-economic variables and 3 bike sharing network variables that we are using in our modelling of daily flows of bike sharing.

Table 2. Descriptive summary of explanatory variables

| Continuous Variables | Min  | Max  | Mean | Std. Deviation |
|----------------------|------|------|------|----------------|
| Population in 300m buffer | 4    | 10977| 4707 | 2478           |
| Employment in 300m buffer | 148  | 11828| 2332 | 2111           |
| Average income in 300m buffer per household | 19963| 36180| 28559| 2944           |
| Elevation of bike sharing station (m) | 164  | 289  | 181  | 28             |
| Station capacity | 10   | 40   | 19   | 6              |
| Number of bike sharing stations in 300m buffer | 0    | 9    | 1.8  | 1.8            |
| Number of bike sharing stations in 3500m buffer | 45   | 277  | 188  | 58             |
| Number of restaurants in 300m buffer | 0    | 28   | 3.1  | 5.3            |
| Number of night clubs in 300m buffer | 0    | 10   | 0.6  | 1.5            |
| Number of cinemas in 300m buffer | 0    | 4    | 0.25 | 0.68           |
| Number of supermarkets in 300m buffer | 0    | 6    | 0.7  | 1.1            |
| Number of shoes and clothes shops in 300m buffer | 0    | 223  | 13   | 33             |
| Number of daily passengers of metro and tramway in 300m buffer | 0    | 43562| 5050 | 8659           |
| Number of daily passengers of railway in 300m buffer (x 5000) | 0    | 20   | 0.26 | 2.0            |
| Length of bike facility in 300m buffer (m) | 0    | 2835 | 1025 | 650            |
| Binary variables | Min  | Max  | Percentage |
| Park in 300m buffer | 0    | 1    | 4%         |
| University in 300m buffer | 0    | 1    | 8.5%       |
| Embankment road | 0    | 1    | 8.5%       |

5. Method

We use a multiple linear regression model to estimate dependent variables such as arrival and departure flows. Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. In this study, the response variable is the daily flows of bike sharing and the explanatory variables are the socio-economic variables determined at station level.
The arrival and departure flows at a daily level for each station were used in the regression model. Let \( i = 1, 2, \ldots, 331 \) be an index to represent each station. The dependent variable (arrival or departure flow) is modeled using a multiple linear regression equation which has the following structure:

\[
Y_i = \beta X_i + \varepsilon
\]

Where \( Y_i \) is the arrival or departure flow at the station \( i \) as dependent variable, \( X_i \) is a vector of explanatory variables determined around bike sharing station \( i \). The model coefficients, \( \beta \), are what we have to estimate. The random error term, \( \varepsilon \), is assumed to have a normal distribution across the dataset. There are 4 principal assumptions that we have to verify in order to validate a multiple linear regression model: (1) normality of residuals, (2) autocorrelation of residuals, (3) homoscedasticity and (4) multicollinearity. If these assumptions are violated, a transformation of variables may be used. In order to ensure the validation of 4 assumptions and the robustness of the model, we have tested many different transformation methods. Finally, the power model seems to be the best choice to achieve linearity for our multiple linear regression analysis. The details of variables transformation are presented in the Table 3.

### Table 3. Transformation of variables for multiple linear regressions

| Variables                                      | Transformation                     |
|------------------------------------------------|------------------------------------|
| Daily inbound flow of bike sharing            | Log(Daily inbound flow of bike sharing) |
| Daily outbound flow of bike sharing           | Log(Daily outbound flow of bike sharing) |
| Population in 300m buffer                     | Log(Population in 300m buffer + 1) |
| Employment in 300m buffer                     | Log(Employment in 300m buffer + 1) |
| Average income in 300m buffer per household   | Log(Average income in 300m buffer per household) |
| Elevation of bike sharing station (m)         | Log(Elevation of bike sharing station (m)) |
| Station capacity                              | Station capacity                   |
| Number of bike sharing stations in 300m buffer| Log(Number of bike sharing stations in 300m buffer) |
| Number of bike sharing stations in 3500m buffer| Log(Number of bike sharing stations in 3500m buffer) |
| Number of restaurants in 300m buffer          | Log(Number of restaurants in 300m buffer + 1) |
| Number of night clubs in 300m buffer          | Log(Number of night clubs in 300m buffer + 1) |
| Number of cinemas in 300m buffer              | Log(Number of cinemas in 300m buffer + 1) |
| Number of supermarkets in 300m buffer          | Log(Number of supermarkets in 300m buffer + 1) |
| Number of shoes and clothes shops in 300m buffer| Log(Number of shoes and clothes shops in 300m buffer + 1) |
| Number of daily passengers of metro and tramway in 300m buffer | Log(Number of daily passengers of metro and tramway in 300m buffer + 1) |
| Number of daily passengers of railway in 300m buffer | Log(Number of daily passengers of railway in 300m buffer + 1) |
| Park in 300m buffer                            | Park in 300m buffer                |
| University in 300m buffer                      | University in 300m buffer           |
| Length of bike facility in 300m buffer (m)    | Log(Length of bike facility in 300m buffer + 1) |
| Embankment road                                | Embankment road                    |

### 6. Results and discussion

In this section, the results of multiple linear regression model estimation are discussed in order to understand the different effects of built environment on the bike sharing usage in the city of Lyon. We tested 4 models in order to estimate the daily inbound and outbound flow of bike sharing. For each type of flow, we present two models: a model using 15 socio-economics variables and the second model using 15 socio-economics variables and 3 bike-sharing network variables. The statistically significant results for these models are presented in Table 4 and Table 5.
Table 4. Model estimation results for daily inbound flows

| Variable                                           | Coefficient of model 2 | Coefficient of model 1 |
|----------------------------------------------------|-------------------------|------------------------|
| Intercept                                          | 4.025                   | 3.277                  |
| Park                                               | 0.006                   | 0.160**                |
| Embankment road                                    | 0.022                   | 0.037                  |
| Night club                                         | -0.014                  | 0.113                  |
| Shoes and clothes shop                             | -0.012                  | -0.040                 |
| Cinema                                             | 0.095                   | 0.123                  |
| Restaurant                                         | 0.045                   | -0.025                 |
| Population                                         | 0.065                   | 0.212**                |
| Employment                                         | 0.117**                 | 0.317**                |
| Income                                             | 0.945**                 | 1.508**                |
| Public Transport                                   | 0.022**                 | 0.029**                |
| Elevation                                          | -4.656**                | -4.661**               |
| University                                         | 0.197**                 | 0.251**                |
| Railway station                                    | 0.011                   | 0.035**                |
| Bike facility                                      | 0.041**                 | 0.065**                |
| Supermarket                                        | 0.139**                 | 0.166**                |
| Number of bike sharing stations in 3500m buffer    | 1.237**                 | -                      |
| Station capacity                                   | 0.014**                 | -                      |
| Number of bike sharing stations in 300m buffer     | -0.192**                | -                      |
| Mean Squared Error (MSE)                           | 0.031                   | 0.051                  |
| Coefficient of determination R2-adjusted           | 86.4%                   | 78.0%                  |

**: significant variable at 99%; *: significant variable at 95%; -: variable non-utilized

In terms of the Mean Squared Error (MSE) and the coefficient of determination of the two models: the model 2 has a better coefficient of determination and a less important mean squared error than the model 1. In this case, an F-test is conducted to see which model is statistically better. It gives a definitive answer and does not rely on arbitrary interpretation of an R2 value or mean squared error. The value of F-statistic is equal to 65.20 and the value of F-distribution is equal to 3.84; this means that the model 2 is statistically better than the model 1; and the 3 variables of bike sharing networks contribute to the improvement of the model. The same F-test was conducted to find the better model between model 3 and model 4; and we found that the model 4 with the presence of 3 bike sharing network variables is statistically better than the model 3. We are going to focus on the influence of explanatory variables on the daily inbound flows of bike sharing. Each group of variables is separately analyzed.

Table 5. Model estimation results for daily outbound flows

| Variable                                           | Coefficient of model 4 | Coefficient of model 3 |
|----------------------------------------------------|-------------------------|------------------------|
| Intercept                                          | -1.372                  | -2.734                 |
| Park                                               | -0.020                  | 0.172*                 |
| Embankment road                                    | 0.019                   | 0.041                  |
| Night club                                         | -0.068                  | 0.089                  |
| Shoes and clothes shop                             | -0.025                  | -0.052                 |
| Cinema                                             | 0.114                   | 0.132                  |
| Restaurant                                         | 0.069                   | 0.002                  |
| Population                                         | 0.030                   | 0.233**                |
Employment  
Income  
Public Transport  
Elevation  
University  
Railway station  
Bike facility  
Supermarket  
Number of bike sharing stations in 3500m buffer  
Station capacity  
Number of bike sharing stations in 300m buffer  
Mean Squared Error (MSE)  
Coefficient of determination R2-adjusted

****: significant variable at 99%; *
*: significant variable at 95%; -: variable non-utilized

### 6.1. Public transport and bicycle infrastructure variables

In terms of public transport variables, we observe that public transport is significant in the two models of regression. It means that public transport system (metro and tramway) has a positive impact on the daily inbound flows. It’s about those who may combine bike sharing with public transport and/or those who may use bike sharing in order to avoid peak period usage in public transport. The variable Railway station is positively significant in the model 1 but is not significant in the model 2. An explanation for this fact is that the introduction of 3 bike sharing network variables hidden the influence of this variable because these 3 variables are important near the railway stations. The daily inbound flows of bike sharing station increase when there are more bicycle facilities nearby a station. This result is corresponding to the findings of Buck et al. 2012 and Faghih et al. 2014.

The 3 variables of bike sharing networks are significant in the model 2 and the model 4. It indicates the bike sharing network variables are important to bike sharing ridership. Bike sharing ridership increases when the capacity of station increases. The impact of the number of stations in a 3500 meter buffer zone and the number of stations in a 300 meter buffer zone need to be examined as a combination: when increasing the number of stations in a 300 meter buffer zone, the number of stations in a 3500 meter buffer zone also increases. So the effect of adding a station is the combination of these 2 variables. In fact, we can see that impact of number of bike sharing stations in 3500 meter buffer zone is 9 times bigger than impact of number of bike sharing stations in 300 meter buffer zone. It highlights that adding more stations is likely to increase bike sharing usage.

### 6.2. Land use and leisure variables

A bike sharing station located in an area with higher population and employment tends to have a higher daily inbound flows. This finding is compatible with the results of Rixey in 2013 and Wang in 2012. It is interesting to see the positive effect of income on the daily inbound flows of bike sharing. This result can be explained by the fact that bike sharing system is installed in the city and the need of credit card in order to be able to use this service. In terms of leisure and shopping variables, we observe that the variable Supermarket is positively significant in the two models. It indicates that bike sharing seems to be used for doing smalls shopping trips because it is difficult to transport a bulky stuff by bike. The other leisure variables like Cinema, Restaurant, and Night club are generally not significant in the four models, except the presence of park near a bike sharing station. This fact indicates that, bike sharing seems to be used mainly for utility trips on a weekday. Bike sharing stations near universities are likely to experience a higher volume of daily flows than bike sharing stations far from universities. The result is corresponding to findings in the Survey of bike sharing...
system of Lyon in 2007 that more than 30% of bike sharing users are student and in agreement with the findings of Faghih et al. 2014 and Hampshire et al. 2012.
In terms of the Elevation variable, the number of bike sharing trips decreases with the increase of elevation. This variable is negatively significant in the model of inbound and outbound flow. This finding suggests that the inbound and outbound bike sharing ridership decrease in hilly zones. The negative effect of elevation on outbound bike sharing ridership can be explained by the fact it is more difficult to find a bike at stations situated in hilly zone due to unavailability of these stations. Bike sharing operators should take into account the effect of elevation for a better regulation of bike sharing.

7. Conclusions
Currently, bike sharing systems have become more and more present all around the world. This trend has led to build models in order to understand the influence of socio-economic characteristics on bike sharing usage and then to quantify the bike sharing flows by using these characteristics. The population, employment, university, park, shops, supermarket are statistically significant while the leisure variables such as cinema, restaurant, night club are not significant in the models suggest that bike sharing seems to be principally used for utility trips during a weekday.
This study also indicates that the bike sharing network variables such as: capacity, number of bike sharing stations in a 300m buffer zone and number of bike sharing stations in a 3500m buffer zone contribute to improve the model. This indicates that a dense and well amenities-connected bike sharing network with a good availability of stations contribute importantly to the increasing of bike sharing ridership.

The models estimated in this study can be directly used for determining the daily flows for an extension of current bike sharing system in the Metropole of Lyon. By eliminating some variables that appropriated to Lyon Metropole such as Embankment Road, these models can be used for positioning and dimensioning stations of a new bike sharing system with available socio-economic data.
Finally, the bike sharing data used in this study are based on mature-adopting bike sharing users; so, traffic planners should be aware that the results of modelling for a new bike sharing system could be different at the starting phase. The same process of analysis in this study can be used for an analysis on a car sharing system in order to understand the influence of different factors of built environment on car sharing usage and to quantify car sharing trips with some adjustments on the size of buffer zone and explanatory variables.

Although these models of bike sharing demand give a very good prediction quality, we can always bring several suggestions for improving the models. Firstly, the models are based on the bike sharing and socio-economic data in 2011. It is preferable to expand the study on a longer period in order to evaluate the temporal transferability of these models. It is interesting to be able to conduct a study on another bike sharing system in France with different sizes of system using the same method in this study. Secondly, a 300m buffer zone was adopted in this study with a hypothesis that the accessibility to a bike sharing station is spatially homogenous. In reality, a buffer zone that corresponds to a 5-minutes or 10-minutes of walking should improve the quality of explanatory variables. There may have other important explanatory variables for bike sharing trips that we cannot introduce in this study such as: weather variables, time of year, seasons, degree, precipitation, visibility of stations, etc. These variables may contribute not only to a better explanation of bike sharing ridership but also a more comprehensible influence of other parameters on bike sharing usage.

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