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Bicycle sharing systems demand

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Abstract

One of the problems in bicycle sharing systems design is the estimation of the potential demand to the service, especially in countries where this type of systems is not yet implemented. The main objective of this methodology is to relate the demand of bike-sharing systems with external characteristics that affects the bicycle usage in order to obtain its territorial distribution. Due to the limited information available in Portugal this paper will focus on the determination of demand based on the experience of other countries. The method is applied to a middle size Portuguese city, Coimbra.

Keywords: Bicycle sharing systems; demand studies; planing; sustainable transport; design.

1. Introduction

The growing need for changes in mobility patterns turns public transportation, bicycle and pedestrian mode the solution to reduce the externalities related with mobility, in particular the consequences of the mass use of fossil fuels, the growing price of the fossil fuels and the excessive occupation of public space by private cars. This can be found in publications such as (Vuchic, 1999) (European Commission, 2009).

Apart from its minimal ecological impact and the reduction of energy dependence, bicycle transportation mode has certain benefits for cyclists, such as improving health and saving money, it provides a significant improvement in the quality of city life and a better experience in the use of urban spaces (European Commission, 1999).

According to European Commission (1999), there is a range in terms of travel time where bicycles are more competitive than any other mode of transport in urban areas (between 2 and 8 minutes). In fact, for trips longer

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than 1.5 km the difference in travel time between bicycle and car is less than 2 minutes, so the bicycle can lose some potential here.

Within the factores that are pointed as reasons to restrict and discourage bicycle use it is often referred the lack of bikeways and other adapted spaces, and consequently, the feeling of insecurity and bad intersections conditions, the distance and the the geographic and weather conditions (European Commission, 1999) (An & Chen, 2006) (Dill & Voros, 2007) (Duthie, Brady, Mills, & Machemehl, 2010) (Heinen, Van Wee, & Maat, 2010).

Weather conditions are a permanent constraint but only under extreme conditions (pouring rain or blistering heat) really discourage cycling. Nevertheless, it is in Northern European countries such as Sweden, where bad weather is very common, that the bicycle has its most devoted users. In fact, 33% of all journeys in Västerås, Sweden (a cold country), are made by bicycle. In Cambridge, United Kingdom, a wet country, cycling accounts for 27% of journeys.

Steep slopes can make the ascents difficult for cyclists and the descents can lead to fast speeds which might be unsafe for cyclists or other users. These situations can be avoided if certain design recommendations are followed, which establish a maximum length according to the slope (AASHTO Executive Committee, 1999). Other solutions help with steep slopes, such as equipping buses with cycle racks, or installing bicycle lifts where the user places a foot in a treadle that pushes them up.

Several cities around the world adopted public bicycle sharing systems as a modal choice; the service allows to pick up and to drop off a bicycle in different stations throughout an urban area. The service allows picking up a bicycle and drop-off in different points (stations) of the city allowing the coordination with other transport modes.

Besides the environmental positive impacts, improvement of city life quality and a better experience in the use of urban spaces, it is expected some alterations in the mobility patterns caused by the implementation of bike-sharing systems. These services capture users from other transport services such as bus transit, walking, autos, and taxis. Furthermore, some authors suggest that bike-sharing acts as competitor and complement of the existing modal options because it can be used as alternative to car and the trips can be complemented with other modes (Shaheen, Zhang, Martin, & Guzman, 2011).

This work to be performed it should provide a methodology to determine the potential demand of bike-sharing services. The bike-sharing systems can be used in two different ways: as an isolated service, or as an intermodal service, complemented with other transport. Besides the demand definition, the methodology should identify the factors that influence the demand and how do they influence it.

This paper proposes a methodology to estimate the demand of a new bike-sharing system in a city, at the level of defining zones with higher potential demand in urban area. The paper is organized into five sections: in section 2 is presented a literature review in bicycle sharing systems mainly in demand studies scope, in section 3 is presented the bike sharing demand methodology, in section 4 the future study case, in Coimbra, is presented and finally the summary and main conclusions are presented in section 5.

2. Literature review

2.1. Bike sharing systems

It is important to distinguish between three generations of services. According with several authors there are three generations of services of bike-sharing: free bike system, coin-deposit systems and information technology-based systems (Shaheen, Guzman, & Zhang, 2010), (Wang, Liu, Zhang, & Duan, 2008) and (DeMaio, 2009).

The free bike-sharing system is characterized by a set of bicycles (with unusual colors and/or shapes) that are available without costs to the user. Typically the stations are located near public facilities that have their own staff which are responsible for the users' identification, reducing the needs of human resources of the system. The use of the bicycle is, in the most cases, free to the user. The first bike sharing system was emerged in

Amsterdam, the Netherlands in 1965. A set of fifty free bicycles was seen as the solution for traffic problems. However the Witte Fietsen (white bikes) Plan failed after its launch due to the bicycle damages and thefts.

In the coin-deposit systems the bicycles are not freely available, once the users have to use a coin to unlock the bicycle from the docking stations. At the same time, some concerns about the location of the stations are introduced to ensure the efficiency of the operation.

Although some significant changes on the motorized transportation patterns in some cities the coin-deposit system did not solved the thefts problem. To overcome this problem, the third generation of bike-sharing emerged based on automatic services.

This generation uses smart technology (mobile phones, mag-stripe cards, smartcards or codes) to unlock the bicycles from the stations allowing the automatic identification of the users (with a code for instance). The casual users pay a security deposit to ensure the return of the bicycle, and the use of the bicycles is paid depending on the time interval of the usage. Typically the service is free in the first specified time interval and the price gradually increases after the interval depletion. This system is simpler to manage in terms of human resources, but requires a higher investment in technology. Some of the great advantages of the technology introduction are the possibility of 24h service, the easier location of stations in the city and the data collection about the usage of the service.

Shaheen, Guzman, & Zhang (2010) identified also the fourth generation of bike-sharing systems. Fourth generation bike-sharing systems are multimodal systems. Their main concern is an improvement of the service to the user needs, in other words it is demand-responsive. It includes an improvement in technological mechanisms in the stations and bicycles that facilitate their use and share, electric bicycles, bicycle relocations and the integration of the several transport services in the same access card (public transportation or car-sharing).

In Portugal it was implemented a free bicycle sharing system in Aveiro, called Bugas, that was launched on April 2000. It stated with a stock of 350 bicycles spread over 33 parks all over the city. However, after the pilot period some of the bicycles were vandalized or stolen. Currently the system works as a less ambitious service with only one station and some degraded bicycles.

The successful of the bike-sharing programs depends on how the demand is satisfied. However, the definition of bike-sharing demand is not yet a popular subject in the literature. Next section provides a literature review about general bicycle demand models and a focus on existing bike-sharing demand definition strategies.

2.2. Demand studies for cycling and bike-sharing

One of the biggest concerns of the urban transportation planners is to provide the most adequate response to traveller's needs, estimating transportation demand and its variation. Planners are also aware of the strong relation between transportation and land use, and as this relation should be incorporated in demand studies.

It is complex and risky to predict the number of bicycle trips, especially in cities where the bicycle is not yet widely used.

There are various studies on the prediction of non-motorized travel demand. Turner, Hottenstein, & Shunk (1997) and (Schwartz et al., 1999) present an overview of different approaches to determine the bicycle travel demand.

One of the methods more frequently referred is the Latent Demand Score Method (Landis, 1996) and it is specially adapted in cases where bicycles are not yet a popular choice. The methodology provides a coefficient of potential demand for bicycle trips throughout a transportation network (in each arc of the network), based on the influence of generator/attractors points in the city on the number of bicycle trips for all road segments. One of the advantages of this model is that it acts as a geographic information system. However the trips estimated are not directional (the method considers the total number of the trips that were generated and attracted), meaning that the method compromises an Origin-Destiny evaluation.

An adaptation of this method was used in a demand study for the city of Tomar (Portugal) where the main difference of this adaptation to the Latent Demand Score Method is that it considers the number of trips in each

origin-destination point, and the choice of shortest path between origin and destination (Ribeiro, Frade, & Correia, 2012).

The current scientific studies or real world applications use 'revealed' or 'stated' preference surveys as methods for bike sharing systems demand estimation (dell'Olio, Ibeas, & Moura, 2011) (ConBici, 2007) (PROBICI team, 2010). In the cases of bike-sharing systems expansion, the revealed surveys can be very useful; however in some cases the responses to the stated preference surveys can be strategic and may not reflect the real intentions of the interviewee. Surveys results must be used with care, mainly in the cases where similar services were not yet implemented.

In order to avoid the constrains caused by the surveys, the demand modelling approach will study different bike-sharing systems around the world defining the profile of the users and potential users, the factors that can influence the demand (as the geographical conditions, the variation of demand during the day or over the seasons, and the travellers characteristics age; sex, and/or job, etc.) and how they affect it.

The demand of New York City bike-sharing system was designed using the user group patterns of successful bike-share programs: Velib'in Paris, Velo'v in Lyon and Bicing in Barcelona; from which three typical user groups were identified: commuters, recreational/errand riders and tourists. The authors estimated the number of people in each potential user category in New York and applied to them different uptake rates (3%, 6% and 9%) to quantify the users of bike-share program. The uptake rates are defined based on London and Paris surveys (NYCDCP, 2009).

Krykewycz, Puchalsky, Rocks, Bonnette, and Jaskiewicz (2010) use a methodology to estimate the demand for a new bicycle-sharing program in Philadelphia (Pennsylvania). The authors' defined two market areas using raster based geographic information system analysis and applied three bike share trip diversion rates determined through surveys in Lyon, Paris (France) and Barcelona (Spain) in order estimate the modal shift from other modes to bike-sharing, establishing different demand scenarios (low, middle and high).

In the Seattle case, the demand study was based in the Philadelphia study. However, the market areas were defined considering a GIS raster dataset of weighted sum indicators that influence bike-share use (population density, non-institutionalized group quarter population density, job density, retail job density, commute trip reduction companies, tourist attractions, parks/recreation areas, topography, regional transit stations, bicycle friendly streets, streets with bicycle lanes and local transit stops). Rates observed in Lyon, Paris and Barcelona, to the defined market areas, were also applied (Gregerson, Hepp-buchanan, Rowe, Sluis, Vander, Wygonik, et al., 2010).

Daddio (2012) presents a regression approach to relate the surrounding characteristics with the station demand. The dependent variable is the number of trip departures per station, using the data provided by Capital Bikeshare (bike-sharing system of Washington Metropolitan Area). The independent variables are measure within 400 meter walk distance from each station. The variables considered are divided in three sets of characteristics: trip generation, trip attraction and transportation network.

In the District of Columbia, the variables statically significant are the population between the ages of 20 and 39, the proportion of population that belongs to a race other than "white alone", the number of retail establishments selling alcohol, the number of metro stations and the distance from weighted mean (ridership) from the center of full DC and CA Capital Bikeshare system.

The use of public bicycles increases potentially when they are complemented with other transportation modes (intermodality), or when parking problems exists in the origin or destination of the trip.

In The Netherlands for instance a growth in bicycle use for non-recurrent trips, besides a reduction in car use and a growth in train trips, was observed after the introduction of a public bicycle sharing service, (Martens, 2007).

Krizek & Stonebraker (2010) presented a methodology - developed for Puget Sound Regional Council in Washington in 2002 - that determines the total number of potential users of a bicycle station (in different scenarios) depending of the respective user groups, defined as: bicycle commuters who work within a quarter mile of the bicycle station; bicycle users who park their bicycles at transit stations and bicycle users who travel with their bicycles. The methodology relates the number of the users with the employment data, the number of

transit trips, the bicycle share within 3 miles of a proposed bicycle station, and the number of bicycle commuters to within a quarter mile of the bicycle station. The validation of this method was done considering the data of two existing bicycle stations and the methodology was considered reasonably accurate.

3. Bike sharing demand definition – a methodology proposal

3.1. Introduction

For the planning of bike sharing systems in a city it is fundamental to define its demand previously. As stated in previous sections, the definition of demand can be done in different ways. One used approach from the previous studies is the use of preference surveys, in some cases the results of preference surveys may be unreliable because the stated behaviour of the respondents may be strategic and not represent their real individual behaviour. The direct comparison with successful implemented bike-sharing systems, as in Barcelona, Paris and Lyon does not relate the demand of bike-sharing systems with other external characteristics that affects the bicycle usage, as the physical characteristics of the city. Then, this methodology proposes a different approach. The main steps of the methodology are referred bellow.

3.2. Methodology

The methodology focuses in the relation between the target public of bike-sharing, trip characteristics and the physical characteristics of the city paths. As previously referred, the bicycle usage is mainly affected by the distance of the trip, the slope inclination, the purpose of the trip and lack of bicycle paths. However it is admissible that, in an urban environment, all streets are adaptable for bicycle use, from minor to major improvements. Therefore, the main advantage of this methodology is not only the demand quantification (which usually is made by applying a bicycle sharing users proportion to all the city trips – to all O-D pairs – only considering different purposes) but also modelling it according the studied area.

The demand definition is studied considering two parts:

a) quantifying demand based on other case studies – obtaining the proportion of bike sharing users per trip purpose and

b) defining, sequentially, the effect on demand caused by the trip characteristics (travel time between traffic zones) and physical city characteristics (slopes).

As final result it will be obtained an OD matrix with bike sharing proportions to the studied area. The main aspects in this methodology are presented in the next subsections and it will be applied to the case study described in section 4.

3.2.1. Purpose

The trip purpose influences the probability of using the bicycle (Marleau, Larsen, & Geneidy, 2011). For instance, the probability of using a bicycle for leisure trips is greater than for shopping purposes, because it can be difficult carrying shopping bags on a bicycle (Mcneil, 2011)(PROBICI team, 2010).

The bike sharing demand is also affected by the trip purpose, as referred, and there are three typical user groups: commuters, recreational/errand riders and tourists. Thus to each one it must be considered different initial rates of bicycle trips (R_n) per purpose (n) based on other study cases.

3.2.2. Distance

For short distances (between 2 and 8 minutes) in urban areas, bicycle can be the most efficient transportation mode. However, while travel distance increases the competitiveness will be negatively affected, and

consequently the potential demand of this mode will decrease: In other words, the potential demand is affected by an elasticity which causes a fall in the percentage of bicycle trips when the distance travelled increases.

The elasticity is the ratio between the variation in the proportion of bicycle trips and the rate variation in travel time, between a reference situation and the desired point.

The elasticity varies with trip purpose, too. The travel time has a different effect according to the travel purpose. For example, two extra minutes on a work journey travel time can significantly reduce the proportion of bicycle users, whereas in recreational travel it may be irrelevant (Heinen, Van Wee, & Maat 2010).

Thus, the percentage of bicycle trips for purpose as a function of travel time, R_{tn}, is calculated by equation (1): very short trips are made on foot thus there is no demand of public bicycles, while there is a range in terms of travel time where the demand of bicycle is maximum however there is an instant time from which it decrease being affected by the elasticity.

$$R_{tn}(t_i) = \begin{cases} 0 & t_i < t_{0n} \\ R_n & t_{0n} < t_i \le t_{1n} \\ R_{tn}(t_{i-1}) + R_{tn}(t_{i-1}) \times E_n \times \dfrac{t_i - t_{1n}}{t_{1n}} & t_i > t_{1n} \end{cases} \tag{1}$$

Where t_{0n} and t_{1n} are the reference instants from each the proportion of bicycle trips starts increasing or decreasing, respectively, and they can vary by trip purpose, t_i is the time travel from each origin to each destination points, R_n is the initial rate of bike-sharing and E_n is the elasticity.

The initial values of E by purpose must be appropriate to each case study. They are strongly dependent on local conditions and personal attitudes to the use of bicycles. These attitudes should be estimated with field surveys or by benchmarking with other examples from around the world. One example is the elasticity values presented to Santander case in PROBICI team (2010).

3.2.3. Slopes

The bicycle sharing systems are specially adapted in case of cities with steep slopes because the cyclists can use bicycle in one direction and use other transport modes (such as buses) for the oposite direction. In these cases the main problem of the bikes-haring systems sponsors is the relocation of bicycles that must be carefully design.

The slopes contribute to the ability of a travel route for cycling, according to (AASHTO Executive Committee, 1999), since grades greater than 5% are uncomfortable for many cyclists (because the ascents are difficult to climb and the descents induce excessive speeds), but they may be used in short sections. As a general guide the authors suggested the reference values of maximum road length for grades greater than 5% presented in Table 1.

The percentage of bicycle trip per purpose is affected by the differences of slopes between origin and destination mainly in cases of ascents.

In order to incorporate the slopes effect in this methodology, each traffic zone is characterized by its roads grades, it means that if the zone has lot of ascendant streets that not to obey to the characteristics in Table 1, the demand of bicycle trips tends to decrease in trips with an undesirable destination.

Table 1. Maximum extension to different slopes, adapted from (AASHTO Executive Committee, 1999).

Grade	Maximum extension
5-6%	240 m
7%	120 m
8%	90 m

9%	60 m
10%	30 m
>11%	15 m

The percentage of bicycle trips for purpose, $R_{sn}(s_i)$, as a function slope characteristics is calculated by equation (2).

$$R_{sn}(s_i) = f_s \times R_{tn} \qquad (2)$$

Where f_s is a factor defined as a function of the undesirable routes proportion and R_{tn} is the percentage of bicycle trips for purpose as a function of travel time.

4. Case Study

4.1. General description

Coimbra is a town located in the center of Portugal and it had more than 140,000 inhabitants in 2011. It is characterized for having a large student population – the University of Coimbra has approximately 30,000 students, being the oldest in Portugal and one of the oldest in Europe.

Coimbra does not meet a set of good infrastructural conditions to make bicycle as an optional transport mode. The lack of bicycle paths, bicycle supporting facilities and streets in steep slopes suggests that Coimbra is not suitable for cyclists. However, there are a lot of paths, with soft slopes, that can easily be adapted for the cycle needs of a growing cycling population.

The latest strategic plans of the city have some points with implications for cycling (Parque Expo, 2012) (Regulamento n.º 255/2012).

In 2008, it was made a study to determine the mobility patterns of its population based on surveys. According this study 42% of the households had one car and about 45% had two or more cars per household, emphasizing the high motorization rate in the city - 522 cars per 1000 inhabitants against 473 cars per 1000 inhabitants in 2009 in Europe (info from Eurostat). Most daily trips are made by car (69%), and bicycle has a very low importance but the study points bicycle as a forthcoming option. About 57% of the trips have less than 4 km.

The mobility study divided the municipality of Coimbra in 61 traffic zones, 29 of which correspond to the city area of Coimbra. The next section presents the mobility characteristics of the city as well as the data bases that will be used in this application.

4.2. Application

The defined methodology is applied to this case study considering the origin destination matrix for the traffic zones of the city of Coimbra, as well as the distances between each traffic zone and its physical characteristics, in a Geographical Information System built for this purpose.

As referred, the typical users of the bike-sharing systems are commuters, recreational/errand riders and tourists. In the Coimbra case study the follow rates of bicycle sharing trips per purpose were considered: (R_n) equals to 3%, 9%, and 6% for commuters, recreational riders and tourists, respectively. These values were taken from a reference study for New York City study case (NYCDCP, 2009).

The influence of **distance** between origin and destination is calculated by equation 1, and considering the values of table 2. The values were based in the Santander (Spain) case.

Table 2. Admitted values of t_{on}, t_{1n}, R_n and E_n.

Purpose	t_{0n}	t_{1n}	R_n	E_n
commuters	1	8	3.0%	-0.08
recreational	1	10	9.0%	-0.01
tourism	1	10	6.0%	-0.01

In order to understand the slope effect of the Coimbra´s irregular orography, the routes in the road network were classified as suitable and unsuitable for cycling according the relation between grade and extension of the roads presented in Table 1. The length proportion of suitable roads in each traffic areas is presented in Fig. 1.

Fig. 1. Traffic zones of the study area classified l by the length proportion of suitable routes.

As show in Fig. 1the orography of the city is very irregular and, consequently, there are zones where is more comfortable to bike (green zones - where near to 100% of road extension respect the relation in table 1) in terms of slopes, on the other hand there are also zones where the major part of the routes are uncomfortable for cyclists (red zones - where only 40 to 50% meet table 1).

The factor f_s of the equation (2) was determinated determined empirically, it should be adjusted through surveys. And it is presented in Table 3.

Table 3. f_s values in function of rate of suitable routes.

Rate of suitable routes		fs
90%	100%	1
80%	90%	0,9
70%	80%	0,7
60%	70%	0,5
50%	60%	0,35
40%	50%	0,2

Fig. 2 (a) presents the total number of trips attracted and generated in each, by all transport modes in the study area and the Fig. 2 (b) presents the results of this methodology application: all the trips simultaneoeusly generated an atractted in each traffic zone, all day, by bike-sharing.
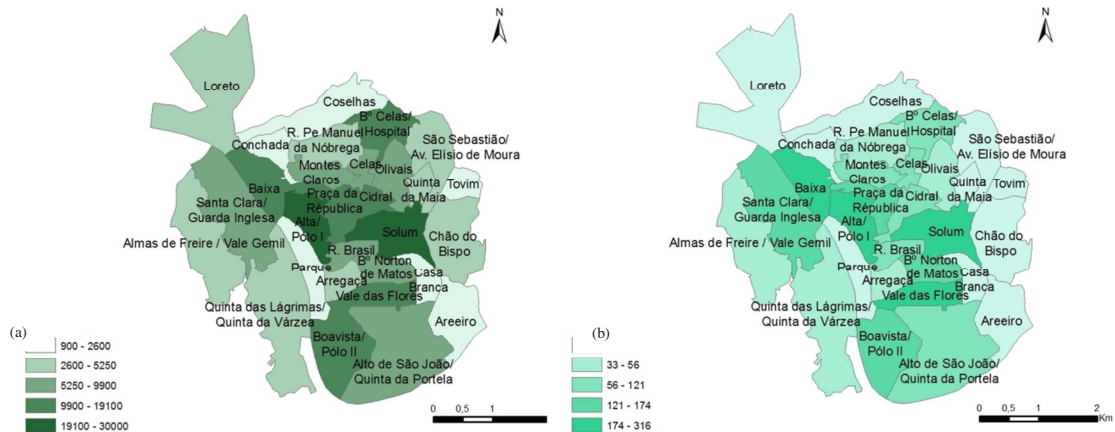

Fig. 2. (a) Total number of trips in traffic zones of study area by all modes; (b) The estimated number of trips in traffic zones of study area using bike-sharing.

From the Fig. 2(a) it is possible to identify two traffic zones with a high number of generated and attracted trips (Alta e Solum), where the Alta area includes the Coimbra University and has about 30000 daily trips.

After the application of the proposed methodology, it is possible to observe some changes in trip patterns: the east traffic zones lose some importance and the 'downtown' and 'Vale das Flores' area gained relevance, Fig. 2(b).

The traffic zones of the mobility study are too large for this type of analysis. Some sensitivity analysis should be developed in further studies in order to see the influence of shortening the traffic areas dimensions on the 'bike-sharing' systems use proportion.

5. Conclusions

This paper sets out a method for estimating the bike-sharing demand and it allows to geo-reference the demand, considering the characteristics of the city and of the trips. This approach was illustrated by an application to the Portuguese town of Coimbra.

The main advantages of this approach are that it provides a quick assessment and it can be adapted to other towns and cities according its characteristics. The method can help in decision-making for transportation planners, policymakers and investors. The method is useful in the full design of the system, including the location of bike-sharing stations and in the dimension of the fleet, as well as in the scheduling of the investments.

Further studies can include the consideration of other socio-economic characteristics, such as population density, non-institutionalized group quarter population density, job density, retail job density, commute trip reduction companies, tourist attractions, parks/recreation areas, topography, regional transit stations, bicycle friendly streets, streets with bicycle lanes and local transit stops, as in the Gregerson, Hepp-buchanan, Rowe, Sluis, Vander, Wygonik, et al. (2010) mention before. It should be also considered the demand associated to public transport, to understand which public transport mode bike-sharing users chose to complete their trip.

Therefore, several information is also being collected in socio-economic variables for each district and each traffic zone that are part of the case study, in order to have a detailed demand determination framework, which is an important part of the formulation in the simulation-optimization model this study aims to reach for.

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