ANALYSIS OF REAL EXPERIENCES USING DIFFERENT SIZED BIKE SHARING SCHEMES IN IRISH CITIES

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ABSTRACT

The first Irish public Bike Sharing Scheme (BSS) was launched in Dublin in 2009. Dublinbikes has been internationally recognised as one of the most successful bike-sharing rental schemes in the world. For this reason, among others, the cities of Cork, Limerick and Galway launched their own BSSs at the end of 2014.

The objective of this paper is to compare the performance of the four BSSs during the first two years of implementation in each Irish city according to endogenous factors, such as the physical design of the schemes, and exogenous factors, such as city size and population density. In terms of population, Limerick and Galway are small cities, Cork is a medium-sized city and Dublin is a large city. In consequence, the results cover the main relevant aspects of BSSs according to the size of the scheme, pointing out similarities and differences among BSS of different sizes. The main findings indicate that the number of daily rentals per bike is a good metric from the point of view of the transport operator. However, a higher density of bikes, stations and docking points does not imply greater usage, whereas the size of the deployment area could be a key factor in improving bike usage. Finally, a synopsis of the essential aspects to consider when designing a BSS deployment based on types of users in small cities is provided.

1. INTRODUCTION

The expansion of Bike Sharing Schemes (BSSs) across the world accelerated when the third generation of such schemes emerged. The third generation of BSSs refers to Information

Technology (IT)- based systems which apply computer technology tools to the operation of the schemes, such as electronic locks, telecommunications systems, smart cards, mobile phones or on-board computers. Moving around the city by bicycle has several advantages; for example, it reduces carbon footprints, reduces car use, provides a last-mile connector mode of transport or develops tourism. These are some of the main reasons why BSSs have grown exponentially around the world (see DeMaio, 2009; Shaheen & Guzman, 2011 or Midgley, 2011 for more detail).

Following this general trend, the first Irish public BSS (Dublinbikes) was launched in Dublin in 2009. Dublinbikes has been internationally recognised as one of the most successful bike-sharing rental schemes in the world, surpassing initial predictions and reaching one million journeys 11 months after its launch. Twenty months later, the two-million mark was attained (according to the reports of the Dublin BSS website: www.dublinbikes.ie). Besides the several advantages cited above, Dublinbike's success inspired the cities of Cork, Limerick, and Galway to launch their BSSs at the end of 2014. These four Irish cities: Dublin, Cork, Limerick and Galway, are the cities under study in this paper.

Recent works have addressed the multi-city scenario of BSSs. BSSs in European cities (for example, London, Barcelona, Paris or Dublin) and North-American cities (Denver, Chicago, Washington D.C. and Miami, among others) are compared to try to understand aspects such as the diffusion patterns of BSSs, considering the characteristics of cities and operator models, learning processes and future developments (see Parkes et al, 2013; Austwick et al, 2013; Sarkar et al, 2015). A global view of bike-sharing characteristics based on data analysed from 38 systems located in Europe, the Middle East, Asia, Australasia and America can be found in the research conducted by O'Brien et al (2014). In this study, the BSSs are characterised on a city level, comparing them in terms of system size, daily usage and compactness, to eventually build a hierarchy of cities sharing similar characteristics. Besides this, Chardon et al (2017) provide a comparison of 75 BSSs, mainly in Europe and North America, using the metric of trips per bike per day.

These studies have attempted to compare very different BSSs, and their main common results are; (i) BSSs are attractive and adaptable urban-mobility systems that are showing rapid development and expansion; (ii) there are a good number of quantitative factors characteristic to BSSs that are easily measurable, however, it is difficult to provide a benchmark to determine the success of BSSs, even when they have no explicit or measurable target; and (iii) the success of a BSS surviving over time depends on policy-makers' goals or other external inputs, such as inclusion within an effective public transport system.

In relation to the lack of a measurable target for some BSSs and their survival over time, this paper aims at pointing out similarities and differences arising from the different sizes of BSSs, mainly in small cities. It generates an open discussion about what the target users of a BSS should be according to the size of the city and its characteristics, in order to achieve a successful BSS that could be maintained over time. Moreover, whether BSS performance in one city could be extrapolated to another city with similar characteristics will be analysed.

Insights on these issues will be obtained from the study of real BSSs in the same country; Ireland. Specifically, the BSS of a large city, Dublin, during the 2009-2011 period; the BSS of a medium-sized city, Cork, during the 2015-2016 period and; the BSSs of two small cities, Limerick and Galway, during 2015-2016 will be analysed, corresponding to the first two years of their implementation in all the cases.

The paper compares how each BSS has performed according to the following differentiating factors: scheme size and density of bikes, stations and docking points (endogenous items) and city size and population density (exogenous items). These observed quantitative factors facilitate a simple comparison of many BSSs to understand each BSS in general terms. From this general perspective, it will be easier to conduct future detailed research.

This paper is structured as follows. Section 2 briefly describes the characteristics of the four Irish cities under study and their BSSs. In Section 3, data analyses focused on the density of bikes, stations and docking points of each BSS and their usage are shown, to finish with a discussion about the relevant issues found. Finally, in Section 4, some conclusions and possible future works are provided.

2. LITERATURE REVIEW AND CHARACTERISTICS OF THE BIKE SHARING SCHEMES STUDIED

2.1 Literature review

Several articles can be found about Irish BSSs; mainly about the Dublin BSS due to its success. For example, O'Neill and Caulfield (2012) analysed the mobility patterns of Dublinbikes during the first stage of the system, and Jiménez et al. (2016) focused on understanding the use of the bike stations according to user mobility patterns in 2015. Murphy and Usher (2015) studied the Dublin BSS from a social point of view, to find out the socioeconomic characteristics of the users, the impact of this mode of transport on modal choice and on driver awareness of cyclists. Caulfield (2014) investigates whether the pro-cycling policies (e.g., bicycle-purchasing schemes, reducing speed limits and the construction of segregated cycle lanes) to promote cycling applied by Dublin Council had an impact on cycling rates during the years after their implementation. Apart from these, this scheme has been researched from an economic point of view by Bullock et al (2017), whose paper places the benefits of BSSs in the economic context of private individual benefits and public good benefits, and they examine the relative value of these benefits and their impact on the spatial functioning of the city. Lawson et al (2013) have looked at the issue from a safety point of view, identifying and analysing the factors influencing cyclists' safety experiences in an urban, signalled multi-modal transportation network in their paper.

With regard to Cork, Limerick and Galway, a Technical Feasibility Study was conducted on the introduction BSSs in these regional cities, which is very useful for understanding the basis of these systems (Jacobs, 2011). Apart from this study, little more can be found about the BSSs of these three cities. Caulfield et al (2017) and McBain and Caulfield (2018) examine the trends of the bike-sharing scheme in the city of Cork, and an MNL Regression model is proposed to predict variations in the journey times of different bike trips based on spatial variables such as bike station location, distance from the city centre and type of services (shops, restaurants, public transport) along the route.

The effectiveness of the BSSs in Limerick and Galway based on station turnover ratios are described by Jiménez et al (2018). Regarding Galway BSS, Maher et al (2016) work with user surveys and stakeholder interviews to understand the beginning of the scheme (from January 2015 to September 2015); and O'Regan et al (2016) analyse the use of a smartphone application to collect rich trip and mode share data from the Limerick BSS to propose a methodology based on current feasibility studies to expand the existing schemes to other neighbourhoods.

Little research can be found related to BSSs developed in small cities. From a multi-city scenario, Audikana et al. (2017) study the Swiss experience with small BSSs spread across different cities to find out about the opportunities and challenges of BSSs in small cities. Among their different conclusions, the authors point out that more research is needed to ensure levels of success similar to medium-sized and large cities, and that partnership, communication and accountability are critical aspects to achieving successful small BSSs.

Thus, the findings of this paper could help to improve BSS performance in small cities, which usually enjoy ease of pedestrian and cycle movement.

2.2 Characteristics of the Irish bike-sharing schemes studied

The main characteristics of each Irish BSS (Dublin, Cork, Limerick and Galway) are described in this section.

Dublinbikes, is a public bicycle rental scheme which has operated in Dublin city since September 2009. At its launch, the scheme used 450 bicycles with 40 stations spread across Dublin city centre. Its acceptance was very positive during the first months. Therefore, in 2010, a mini-extension was made with 4 stations and 100 more bikes. Thus, during its first stage, Dublin Bikes consisted of 44 bicycle stations and 550 bicycles, with an estimated deployment area of 8.75 km^2; approximately 7.5% of the total area of the city (see Figure 1a). The subsequent extensions counted on up to 101 bike stations and 1,500 bikes (www.dublinbikes.ie), which increased this scheme to 20 km^2; about 17% of the total metropolitan area. In order to compare results at the same level as other cities; that is, after two years of the BSS implementation, the data collected from Dublin are related to the year 2011, considering the data of the first period of the scheme.

Figure 1b shows the deployment area of the scheme, the location of the 44 bike stations, the third-level campus located in the area, i.e., Trinity College Dublin, and the defined attraction area of the city. The attraction area includes numerous banks, offices, shopping centres, museums, tourist attractions, restaurants, cafés, clubs, hotels, pedestrian areas and green areas. That is to say, the attraction area has been defined by the high density of services offered. Most of the bike stations are located within the attraction area. They give access to businesses, shops, restaurants, tourist attractions and services, except the northern part of the system, which serves a more residential area.

The deployment area of 2.5 km per 3.5 km provides an appropriate distance to cross the city by bicycle with an average travel time of 12 minutes.

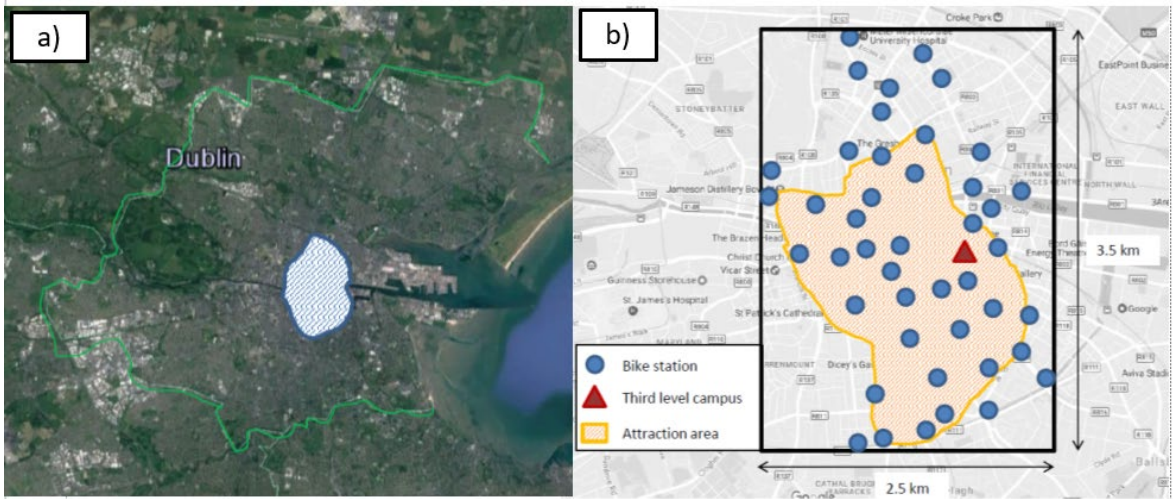

Fig. 1 – a) Dublinbikes deployment area in 2011. b) Detail of Dublinbikes extension in 2011. Source: Google maps. Digital globe 2016.

Cork's *Coca-Cola Zero Bikes* has operated in the city since December 2014. At its launch, the scheme used 330 bicycles with 31 stations spread across Cork city centre. It is estimated that the area occupied by this scheme is 2.5 km^2; approximately 6.5% of the total area of the city (Figure 2a), which is very similar to the first stage of the Dublin BSS.

Figure 2b shows the deployment area of the scheme in the main part of the Cork city centre (on the island between the two river channels), the location of the 31 bike stations and the third-level campus located in the southwestern part of the area, University College Cork. Most of the bike stations are located within the attraction area. Therefore, they give access to businesses, shops, restaurants, tourist attractions and services, but the scheme is enlarged to the Northeast to give access to the train station, and to the Southwest to cover the university, typically associated with higher BSS demand. The extension of this deployment area of 2.5 km per 1 km also provides the appropriate distance to cross the city by bicycle with an average travel time of 7 minutes; probably shorter distances than the Dublin scheme, but still efficient for bicycles.

Fig. 2 – a) Cork Bikes extension in 2016. b) Detail of Cork Bikes extension in 2016. Source: Google maps. Digital globe 2016.

Limerick's *Coca-Cola Zero Bikes* has operated in the city since December 2014, like the Cork BSS. The scheme uses 215 bicycles with 22 stations spread across Limerick city centre.

It is estimated that the area occupied by this scheme is 3 km^2; approximately 10% of the total area of the city, and the largest area of the four Irish cities at the beginning of their BSS implementation (Figure 3a). The deployment area of the Limerick scheme, the city centre, is shown in Figure 3b, together with the location of the 22 bike stations. Most of the bike stations are located within the attraction area. They give access to businesses, shops, restaurants and tourist attractions, although the scheme has some bike stations near to residential neighbourhoods in the East and Southwest. The extension of this deployment area of 1.5 km per 2 km is within the limit of an appropriate distance to go by bicycle. This means that to ride 2 km across the city takes 8 minutes with an average speed of 15 km/h (comfortable speed), whereas walking these 2 km across the city takes 24 min (average speed of 5 km/h for pedestrians). Generally, half an hour is the maximum time commuters will consider walking. Thus, it can be said that a distance of 2 km is the lower limit for the use of bicycles because distances lower than 2 km are also comfortable to walk, and people would not have to change their mode of transport. Note that this BSS does not cover the demand of the University of Limerick, located about 6 km from the city centre towards the East.

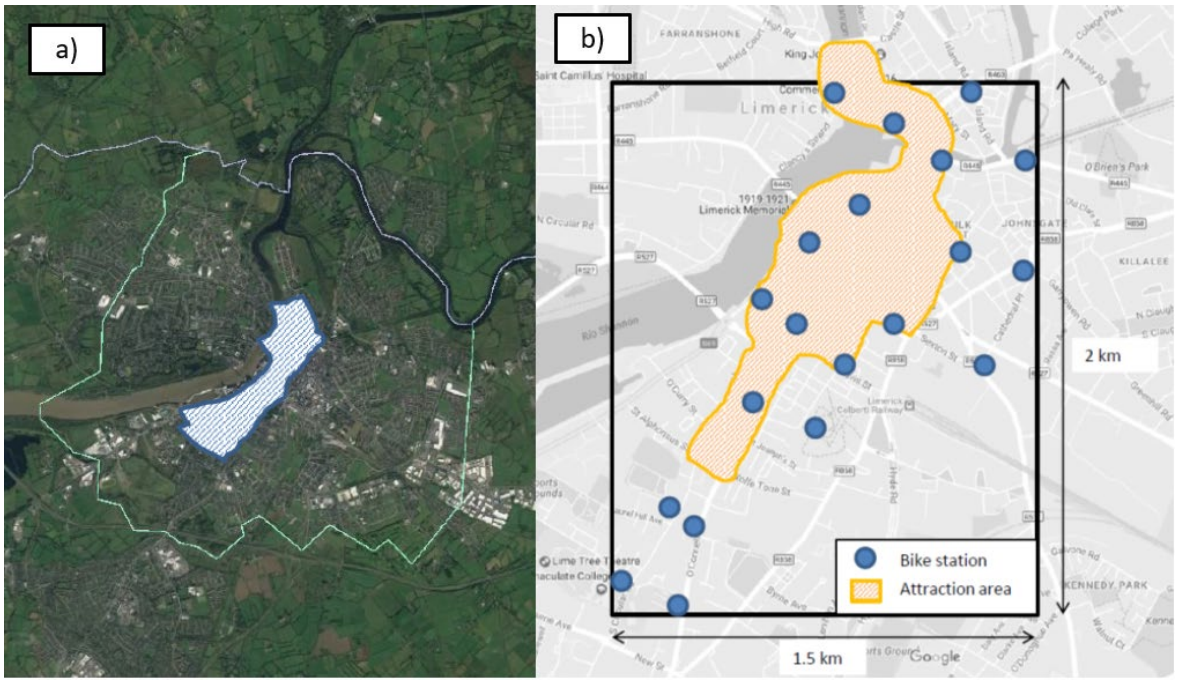

Fig. 3 – a) Limerick Bikes extension in 2016. b) Detail of Limerick Bikes extension in 2016. Source: Google maps. Digital globe 2016.

Galway's *Coca-Cola Zero Bikes* has also operated in the city since November 2014. The scheme uses 195 bicycles with 15 stations spread across Galway city centre. It is estimated that the area occupied by this scheme is 1.2 km^2; approximately 2% of the total area of the city, the lowest value among the four cities (Figure 4a). The deployment area of the Galway scheme, as well as the city centre, is shown in Figure 4b, together with the location of the 15 bike stations. Most of the bike stations are located within the attraction area. This means they give access to businesses, shops, restaurants and tourist attractions. Related to the third-level campus, the location of a bike station near the Galway Technical Institute (lower left corner) and the lack of them near the National University of Ireland - Galway (upper left red point in Figure 4b) stand out because universities are a source of potential bike-sharing users. On the other hand, the extension of this deployment area of 1 km per 1.2 km is also remarkable because the possible distance covered by bicycle (an average travel time of 5 min from extreme to extreme) can also be done by walking; thus, people might not be encouraged to use bicycles in the same way as in Limerick.

Note that in these specific cities, university campuses are relevant to understanding current and future BSS usage because (i) the scheme is used by students, faculty and staff members to access the university, (most of them combine bicycles with the train if they live in the outskirts), (ii) the bike stations related to these universities become part of the general scheme of the city, (iii) the universities are tourist attractions, especially in Dublin and Cork, and (iv) the students living on university campuses use bikes to move around the city.

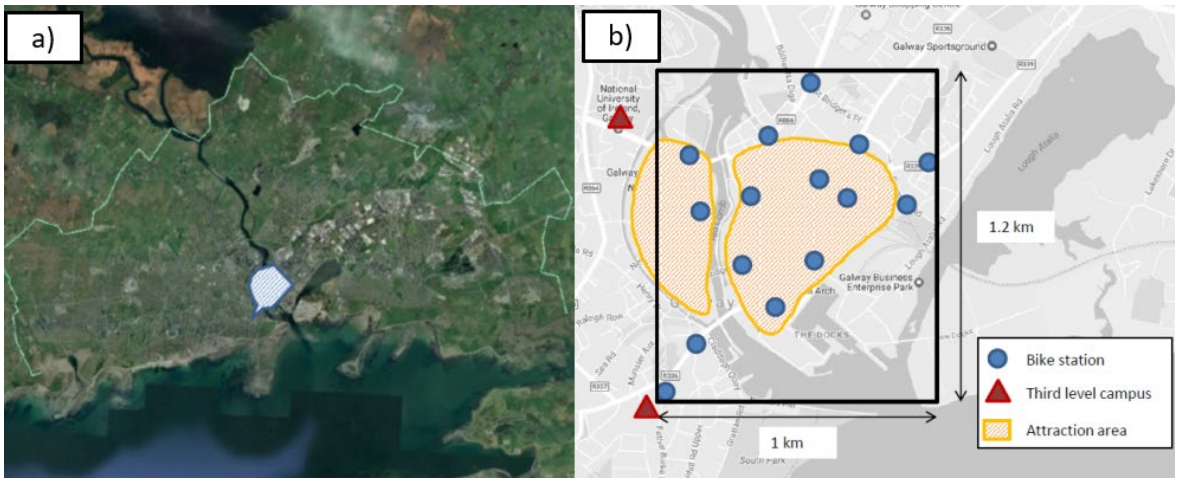

Fig. 4 – a) Galway Bikes extension in 2016. b) Detail of Galway Bikes extension in 2016. Source: Google maps. Digital globe 2016.

Table 1 provides data about population density, potential BSS users (considering that citizens between 20 and 39 years old are the main target group for bicycle usage on a daily basis), the area of the city occupied by the scheme and the number of bikes, stations and docking points of each BSS for each city. From this table two aspects are highlighted: (i) Dublin, Cork and Limerick have greater population density than Galway, and (ii) the percentage of the city area with bike stations during the first stage in all the cities could be considered to be similar, except for Galway. Galway has a low value with 2.4% of the area with bike stations; 5 points below the percentage of the first stage of *Dublinbikes*, and 8 points below the Limerick BSS. Both issues are important because they could affect the usage of the system in each city.

	Dublin 2011	Cork 2016	Limerick 2016	Galway 2016
Population (inhabitants)	527, 612	125, 657	94, 192	78, 888
Area of the city (km^2)	116.58	38.59	28.38	50.00
Population density (inh/km^2)	4, 526	3, 256	3, 319	1, 578
Main potential BSS users (20-39 years old)	208, 489	44, 561	26, 033	30, 693
% main potential BSS users over the total population	39	35	28	39
Area of the city with bike stations (km^2)	8.75	2.50	3.00	1.20
% area of the city with the bike stations over all area	7.51	6.48	10.57	2.4
BSS basic data				
Number of bikes	550	330	215	195
Number of stations	44	31	22	15
Number of docking points	1, 145	574	406	250

Table 1 –Basic demographic data and number of bikes, bike stations and docking points for each Irish city studied. Data source: Census 2011 and 2016 of Ireland and Northern Ireland. Central Statistics Office. *Dublinbikes. Coca Cola Zero bikes*.

3. DATA ANALYSIS

3.1. Research context

This paper focuses on a multi-city scenario (most of them small to medium-sized) within a country to identify similarities and differences among the different sizes of BSSs. Also, the role of BSS target users in relation to a city's size and its characteristics are investigated to see what makes a BSS successful over time. Moreover, the question about whether the BSS performance of a consolidated scheme, such as *Dublinbikes*, could be extrapolated to other schemes with similar characteristics except city size, will be analysed.

To achieve these objectives, the European research study, Optimising Bike Sharing in European Cities – A Handbook (OBIS, Büttner et al 2011) has been taken as a reference. Its main objective is to encourage the implementation and optimisation of BSSs all over Europe and worldwide. This project collects relevant information about more than 50 BSSs from different European countries. Data are analysed and the results presented according to city size, providing a good overview and guidance for cities with similar conditions.

Therefore, according to their population and the definition of the OBIS project, Limerick and Galway are small cities because their population is between 20,000 and 100,000 inhabitants, Cork is a medium-sized city because its population is between 100,000 and 500,000 inhabitants and Dublin is a large city with a population greater than 500,000 inhabitants (Table 1).

Furthermore, the OBIS document gathers factors influencing BSSs, which are divided into endogenous and exogenous factors. This classification is used as the guide to select the factors analysed in this paper.

Regarding endogenous factors, only the physical design of the schemes (size and density) is analysed because it is the main differentiating factor among the BSSs involved. The rest of the endogenous items are similar for the four BSSs. All the services are available all year round, 7 days a week, from 5 am to 00.30 am, though a bike can be returned to available stands at any time of day or night.

They all offer two types of registration; annual subscription and 3-Day subscription for occasional short-term use or for visitors to the cities. Thus, all stations are equipped for Annual Card and 3-Day Ticket users because the hardware and technology consist of card-based access in each station. The first 30 minutes of each hire is free. For longer hires, a charge is applied.

With reference to exogenous factors, city size is the most relevant. The other exogenous factors such as climate, topology, economy and policy exhibit secondary importance. In fact, climate is not a key factor because the weather is similar in all four cities.

They have a mild oceanic climate with abundant rainfall and a lack of extreme temperatures. Thus, the use of bicycles is typical of warm cities with regular use all year and a slight fall in winter and summer (according to the description of the OBIS document). In relation to general geographical factors, all the cities have a main river and/or river channels, they are not hilly, the bikes are integrated into the traffic flow (except in Dublin, where there are a few segregated cycle lanes), and the core of the bicycle scheme is located in the main attraction area of the city (with several businesses, restaurants, shops, tourist attractions and services).

Thus, the cities depart from a similar starting point in terms of local conditions. However, the size of the deployment area and its extension into residential areas or university campuses are different in each city, and these will be the aspects to compare and explain.

In particular, the density of the bikes, stations and docking points of each BSS related to the population, the entire city area and the city area with bike stations, together with other ratios regarding the docking points are analysed. These figures provide a general view of the scale of bicycle-sharing network coverage (relatively dense), allowing comparison with average European values (according to the OBIS document), which are helpful in understanding the possible relationship between BSS coverage scale and the usage and development of the schemes. With regard to BSS usage, the data are divided according to the type of user (annual or occasional).

An estimation of the degree of success of a BBS will depend on the point of view of the stakeholders. In this case, the point of view is the transport company's, based on the usage and efficiency of the systems, which is understood as the number of daily rentals per bike.

The aggregated data used in this study allows for the estimation of the degree of success from this perspective. The larger the values, the more successful the system is. This criterion is widely used because it is an easily comparable measure. Besides, it is of interest to identify possible patterns in the usage data of the first years of BSS implementation in the four cities and to find specific characteristics of BSSs in small cities.

3.2. Dataset description

The dataset has been obtained by open sources and previously published manuscripts. The data related to Dublinbikes are obtained through the reports available on its website (www.dublinbikes.ie), and in the cases of Cork, Limerick and Galway BSSs, from the reports available on the common website (www.bikeshare.ie). In addition, the provided data from Caulfield et al (2017) and McBain and Caulfield (2018) are consulted to complete Cork bike information, whereas for the BSSs of Limerick and Galway, data from Jiménez et al (2018) are also used.

The proposed approach is not data intensive. Thus, it is easily scalable by adding new cities, and allows a good picture of the main BBS characteristics without overwhelming the analyst with an overly extensive list of indicators.

3.3. BSS infrastructure

In order to compare the four BSSs, the density of bikes, stations and docking points of each BSS are calculated. Table 2 provides the main results in relation to the density of each bike, station and docking point over the population, over the entire area of the city and over the deployment area of the scheme. The ratios regarding docking points based on the figures of Table 1 are also analysed.

	Dublin 2011	Cork 2016	Limerick 2016	Galway 2016
Bike/station/ docking point density over population				
Number of bikes / 10, 000 inhabitants	10	26	23	25
Number of stations / 10, 000 inhabitants	0.8	2.5	2.3	1.9
Number of docking points / 10, 000 inhabitants	22	46	43	32
Bike/station/ docking point density over the whole city area				
Bike density (unit/km^2)	4.72	8.55	7.58	3.9
Station density (unit/km^2)	0.38	0.80	0.78	0.30
Docking point density (unit/km^2)	9.82	14.87	14.31	5.00
Bike/station/ docking point density over the city area with bike stations				
Bike density (unit/km^2)	62.86	132.00	71.67	162.50
Station density (unit/km^2)	5.03	12.40	7.33	12.50
Docking point density (unit/km^2)	130.86	229.60	135.33	208.33
Ratios regarding docking points				
Number of docking points / bike	2.1	1.7	1.9	1.3
Average number of docking points / station	26	18	18	17
Standard deviation of docking points / station	5.5	6.6	4.5	3.8

Table 2 –Scheme size and density of bikes/stations/docking points of BSSs for each Irish city studied.

In relation to the density of bike/station/docking points over the population, the Cork, Limerick and Galway BSSs (the medium-sized and the two small-sized, respectively) have approximately double the value than the Dublin BSS This means that they provide more physical components per inhabitants. The figures of these three cities are also higher than the average values indicated in the BSS key figures of the OBIS sample (14.8 bikes per 10,000 inhabitants and 1.5 stations per 10,000 inhabitants), whereas Dublinbikes is below these references.

When comparing the schemes according to city area or the deployment area of the BSSs, two aspects are highlighted. The first one is that Cork and Limerick's ratios of bike/station/docking point density over the entire city area stand out above the rest, and the second one is that the ratios of bike/station/docking point density over the deployment area of the BSSs are similar between Cork and Galway, and, in turn, higher than Dublin and Limerick's.

Ratios of docking points show that each bike has roughly two docking points. However, the ratio in Galway is close to one; the minimum value required to be able to operate. However, it corresponds to the figure in the OBIS document (1.2) for this item in small cities.

Concerning the capacity of the stations, the Dublin bike stations are bigger than the bike stations in the other cities; that is, they have more docking points. Interestingly, the capacity data are opposed to the sample given in the OBIS project, where results show an average of 9.5 docking points per station for large cities and 23.5 and 22.9 docking points per station for medium-sized and small cities, respectively.

3.4. BSS usage

Regarding the usage data shown in Table 3, three aspects are highlighted.

The first feature is the large number of trips in Dublin; four times greater than Cork, thirty-five times greater than Limerick and almost seventy-seven times greater than Galway. This figure is closely related to the number of users; that is, there are four times more users in Dublin than in Cork, and about twenty times more than in Limerick and Galway.

The second aspect to point out is the share of annual and occasional users. Dublin and Galway BSSs have a large number of tourists since occasional users are 40% of the total. However, the Limerick BSS has high annual user demand, with these users making up 90% of the total. Similarly, regarding the total number of trips during the two first years of implementation, the average number of daily trips is greater in Dublin, and this value decreases according to the size of the BSS.

The third point to highlight is related to the daily rental ratio per bike. Specifically, the low values in Limerick and Galway show practically no daily use of bikes.

This indicates that the trips and users are insufficient to keep a steady level of usage throughout the year, and use is concentrated over several months in spring and autumn. Thus, neither of these systems are considered to be efficient in terms of the regular usage of the scheme.

	Dublin 2009-2011	Cork 2015-2016	Limerick 2015-2016	Galway 2015-2016
Total number of trips	2, 500, 000	518, 000	71, 595	32, 460
Total number of users	62, 000	N.A.	3, 230	2, 743
% Annual users	60	N.A.	90	64
% Occasional users	40	N.A.	10	36
Average daily trips	3, 425	710	98	44
Daily rental per bike	6.2	2.2	0.5	0.2
Average number of trips per user (all types of users)	40	N.A.	22	12

Table 3- Usage of each BSS studied. (N.A. – Not available)

3.5. Discussion

Dublinbikes, a large city scheme, has been well received by society. Proof of this is the second enlargement of the system in 2014. Some of the main reasons are (i) Dublin's high population density, 4,526 inh./km2 in 2011 (see Table 1), and (ii) the size of the deployment area of the BSS; that is, the extension area where the bike trips are efficient and can be combined with trips on foot and by car to access work or when enjoying leisure activities.

Additionally, other characteristics and practical measures such as the percentage of young population, cycling facilities, 30 km/h zones, communication campaigns and council favour, have supported its development. However, the values of the density of bikes, stations and docking points over the population and the entire city area are lower than the values of the other three cities and the reference values of the OBIS document.

Related to Cork, a medium-sized city, when comparing the data of trips and population with the data of trips and population in Dublin in 2011, the same proportion is shown. Thus, the same trend experienced by Dublin could be expected there. Some of the main reasons for achieving these numbers of trips and users could be the city's population density and the deployment area of the BSS. Indeed, this area is within the limit of efficient bike trips; that is, an area of 2.5 km^2 providing appropriate distances to cross the city by bicycle with an average travel time of 7 minutes (in an area smaller than 2.5-3.0 km^2, the possible routes are also appropriate for walking, and the impact of the scheme might be lower due to the low level of usage).

Usage is reinforced with the university connection, which provide an important group of system users. Note that neither Limerick nor Galway have bike stations near their university campuses.

The findings of this paper show that usage in Galway and Limerick is lower than in the other Irish schemes, with average daily bike rental near zero (Table 3). One possible strategy to increase this usage could be to expand the scheme.

This coverage growth could result in an upturn in usage numbers. Considering that both cities have small deployment areas in the schemes, a modal shift from pedestrians to cyclists is complicated. Moreover, a large group of potential demand, the staff and students of the universities, are outside of both BSSs. However, the cities have different characteristics.

Limerick has similar population density to Cork, whereas Galway has lower population density than the other cities. The type of users in each city is also different. This indicates that the development of each BSS for the short-term should be addressed from different perspectives according to the characteristics of each target group.

The main outcomes of the analysis based on real experiences could be summarised as follows:

- Only data from Dublinbikes could be partially comparable to the Cork scheme (medium-sized city), according to the ratio of number of trips and population, which have the same proportion. Moreover, deployment areas have a large enough extension to encourage bike usage, being close to the university.

- The number of daily rentals per bike is the most objective indicator of success in relation to usage from the perspective of the transport operator. Thus, the schemes of Dublin and Cork have good performance, whereas Limerick and Galway show a value below 1 (some bikes are unused each day).

- A higher density of bikes, stations or docking points does not imply greater usage; whereas the size of the deployment area could be a key factor in improving bike usage.

- BSS performance in small cities should not be compared with the BSSs of large cities by means of only quantitative data.

The identification of a successful BSS is indeed a difficult issue to solve because each city is conditioned by many aspects such as the characteristics of the surrounding area, the initial scenario of implementation and operational management. Moreover, the success of a system cannot be based only on a single ratio (e.g., number of daily rentals per bike) despite its good performance. In fact, the success of a BSS will depend on the desired goals of the council or the promoting body of the project in the short and long term and on the indirect benefits expected. That is, assessing whether a BSS is successful or not will depend on *what* and *who* it is for. Therefore, and according to the obtained results, the question to answer is how to improve the performance of BSSs in small cities. To answer this question, some considerations were analysed, from which Figure 5 emerges.

Figure 5 shows a synopsis of key aspects and recommended questions to consider before designing a BSS deployment or when improvements are desired after a few years of working. The identification of city characteristics from the point of view of the offer available is the first analysis to carry out; that is, to identify the attraction areas of the city such as business areas, third-level campuses, shopping areas, outdoor leisure and indoor zones and museums and areas of cultural activities. Next, the generation areas are also determined, such as residential and tourist accommodation areas, to consider that all attraction areas become generation areas when they are the origin of the trip.

Geographical barriers are also described to discover uncomfortable paths, inaccessible areas or critical points in bicycle trips. Space syntax would be a useful tool for this purpose. At the same time, the potential users, residents and/or tourists are also identified, in addition to the definition of the attraction and generation areas involved with each one (right upper corner of Figure 5). For example, the main attraction areas for residents are the business areas and third-level campuses because they make these trips on a daily basis, although they also visit the rest of the identified attraction areas during their leisure time. However, tourists are usually interested in visiting all types of leisure areas and places with cultural activities.

Once all these elements have been identified according to the target user of the BSS, some questions should be considered to design an adequate deployment area able to attract users and make the BSS profitable. As the lower part of Figure 5 shows, if the main target users are residents, the key is the extension of the deployment area to make bicycle trips efficient; that is, there will be sufficient bicycle stations to link residential areas with attraction areas. Moreover, the distance should be far enough to make the trip by bike worthwhile.

This type of user guarantees a steady level of usage, although detailed studies on seasonality and student mobility patterns should be developed to continue improving the scheme. If the target users are tourists, becoming aware of the seasonality of their visits is essential to understanding the usage of the system, as might be Galway's case in the first stage. In this case, the deployment area would be less important because tourists usually make circular trips, enjoying the city while stopping for sightseeing and shopping, so they use the BSS in a different way than residents. Finally, if the BSS covers both types of users, in addition to the two previous questions, it is important to identify possible overlapping between resident and tourist attraction areas to be able to take advantage of this overlapping and make the BSS more profitable. Obviously, these are general considerations that help in initiating the layout of a BSS in small cities. They should be complemented with specific studies for each city.

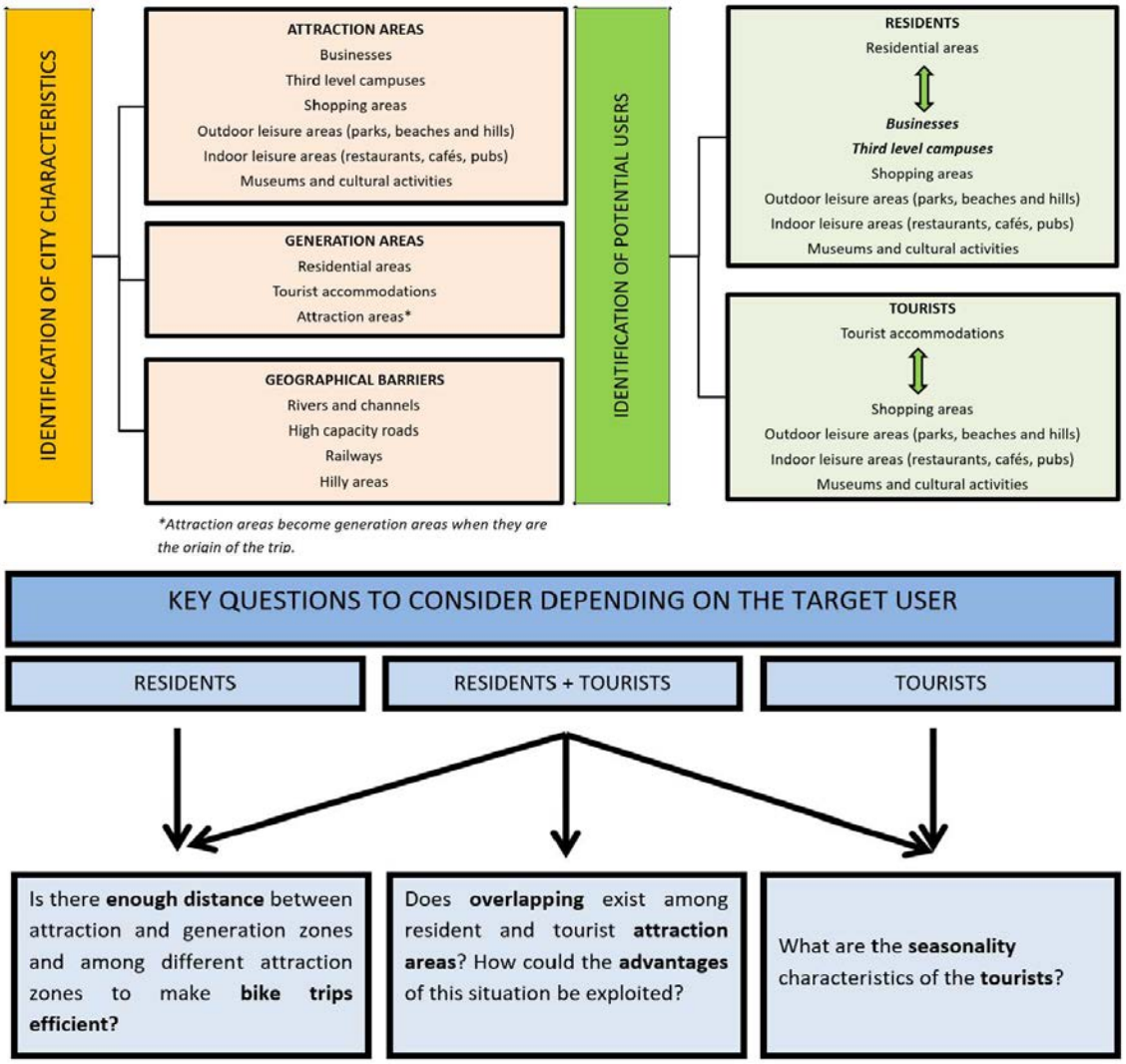

Fig. 5 – Synopsis of key questions to consider when designing a BSS deployment area in small cities.

4. CONCLUSIONS

A BSS in Dublin (large city), a BSS in Cork (medium-sized city), and two BSSs in Limerick and Galway (small cities) have been analysed during their first two years of implementation to try to understand how the size of the city and its scheme could affect the usage of each BSS.

The number of daily rentals per bike is a good metric from the point of view of the transport operator. However, a higher density of bikes, stations or docking points does not imply greater usage, whereas the size of the deployment area could be a key factor in improving bike usage.

In general terms, the development and operation of BSSs in medium-sized to large cities are usually satisfactory because of the high population density, the several groups of interest and the suitable distance covered by bicycle trips. In contrast, the usage level of BSSs in small cities is different from large cities because the deployment area is usually inefficient for bicycle trips and the management of potential users is not adequate. Thus, based on these current experiences, to extrapolate general results from the BSSs of large cities to schemes in small cities would not be recommendable.

Improving BSS performance, mainly in small cities, requires the identification of the city's characteristics from the point of view of the offer available, attraction and generation areas, along with possible geographical barriers and the identification of the potential users, residents and tourists. All these elements could help to guide the initial design or new measures to put into practice to improve BSS performance in the short term.

In fact, studying the first two years of BSS implementation in small cities is very helpful to be able to understand the mobility patterns of users and how to manage a BSS to obtain successful operation in the future. Developing a BSS depending on the characteristics of the main group of users registered during the studied period, i.e., annual or occasional users, to achieve the desired results in the short term, and then expanding the system to other types of users if desired, is recommended. Thus, studies on each group of specific users and how to adapt BSSs to them in small cities will be the next topic to research in order to improve the knowledge in this area and to be able to adapt better schemes to achieve efficient and profitable results. For these studies, not only the identified critical issues should be considered, but also how to improve cycling infrastructure, new 30 km/h zones or communication campaigns for the development and operation of small BSSs.

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REFERENCES

AUDIKANA, A., RAVALET, E., BARANGER, V. AND KAUFMANN, V. (2017). Implementing bikesharing systems in small cities: Evidence from the Swiss experience. Transport Policy, 55, pp.18-28.

AUSTWICK, M. Z., O'BRIEN, O., STRANO, E. AND VIANA, M. (2013). The structure of spatial networks and communities in bicycle sharing systems. PloS one, 8(9):e74685.

BULLOCK, C., BRERETON, F. AND BAILEY, S. (2017). The economic contribution of public bike-share to the sustainability and efficient functioning of cities. Sustainable Cities and Society, 28:76-87

BÜTTNER, J., MLASOWSKY, H., BIRKHOLZ, T., ET AL. (2011). Optimising Bike Sharing in European Cities-A Handbook. OBIS project.

CAULFIELD, B. (2014). Re-cycling a city: examining the growth of cycling in Dublin. Transportation Research Part A: policy and practice, 61:216-226.

CAULFIELD, B., O'MAHONY, M., BRAZIL, W., & WELDON, P. (2017). Examining usage patterns of a bike-sharing scheme in a medium sized city. Transportation research part A: policy and practice, 100, 152-161

DE CHARDON, C. M., CARUSO, G., AND THOMAS, I. (2017). Bicycle sharing system success determinants. Transportation research part A: policy and practice, 100:202-214

DEMAIO, P. (2009). Bike-sharing: History, impacts, models of provision, and future. Journal of Public Transportation, 12(4):41-56.

JACOBS (2011). Proposals for Introducing Public Bike Schemes in Regional Cities – Technical Feasibility Study. In Jacobs Engineering Ireland Ltd.

JIMÉNEZ, P., NOGAL, M., CAULFIELD, B. AND PILLA, F. (2016). Perceptually important points of mobility patterns to characterise bike sharing systems: The Dublin case. Journal of Transport Geography, 54:228-239.

JIMÉNEZ, P., NOGAL, M., & CAULFIELD, B. (2018). Effectiveness of Small Scale Bike Sharing Systems According to the Analysis of Turnover Station Ratios. Annual Meeting Transportation Research Board. Washington D.C. USA.

LAWSON, A. R., PAKRASHI, V., GHOSH, B. AND SZETO, W. (2013). Perception of safety of cyclists in Dublin city. Accident Analysis & Prevention, 50:499-511.

MAHER, C., MANTON, R. AND FAHY, F. (2016). A mixed-method analysis of the Galway bike share scheme using stakeholder interviews, user surveys and trip data. In Proceedings of the ITRN2016 - Irish Transport Research Network.

McBAIN, C., & CAULFIELD, B. (2018). An analysis of the factors influencing journey time variation in the cork public bike system. Sustainable cities and society, 42, 641-649.

MIDGLEY, P. (2011). Bicycle-sharing schemes: enhancing sustainable mobility in urban

areas. United Nations, Department of Economic and Social Affairs, pages 1-12.

MURPHY, E. AND USHER, J. (2015). The role of bicycle-sharing in the city: Analysis of the Irish experience. International Journal of Sustainable Transportation, 9(2):116-125.

O'BRIEN, O., CHESHIRE, J. AND BATTY, M. (2014). Mining bicycle sharing data for generating insights into sustainable transport systems. Journal of Transport Geography, 34:262-273.

O'NEILL, P. AND CAULFIELD, B. (2012). Examining user behaviour on a shared bike scheme: the case of Dublin Bikes. 13th International Conference on Travel Behaviour Research.

O'REGAN, L., COSGROVE, T. AND HIGGINS, R. (2016). Generating rich trip data using smartphone applications to facilitate feasibility studies for bicycle sharing schemes. In Proceedings of the ITRN2016 - Irish Transport Research Network.

PARKES, S., MARSDEN, G., SHAHEEN, S. A. AND COHEN, A. P. (2013). Understanding the diffusion of public bikesharing systems: evidence from Europe and North America. Journal of Transport Geography, 31:94-103.

SARKAR, A., LATHIA, N., AND MASCOLO, C. (2015). Comparing cities cycling patterns using online shared bicycle maps. Transportation, 42(4):541-559.

SHAHEEN, S. AND GUZMAN, S. (2011). Worldwide bikesharing. Access Magazine, 1(39). https://www.accessmagazine.org/fall-2011/worldwide-bikesharing/