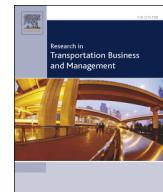




Contents lists available at ScienceDirect

## Research in Transportation Business &amp; Management



## Bike sharing: A review of evidence on impacts and processes of implementation and operation

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## ARTICLE INFO

## Article history:

Received 13 February 2015

Received in revised form 29 March 2015

Accepted 30 March 2015

Available online xxxx

## Keywords:

Bike sharing

Cycling policy

Evidence

Evaluation

## ABSTRACT

Despite the popularity of bike sharing, there is a lack of evidence on existing schemes and whether they achieved their objectives. This paper is concerned with identifying and critically interpreting the available evidence on bike sharing to date, on both impacts and processes of implementation and operation. The existing evidence suggests that bike sharing can increase cycling levels but needs complementary pro-cycling measures and wider support to sustainable urban mobility to thrive. Whilst predominantly enabling commuting, bike sharing allows users to undertake other key economic, social and leisure activities. Benefits include improved health, increased transport choice and convenience, reduced travel times and costs, and improved travel experience. These benefits are unequally distributed, since users are typically male, younger and in more advantaged socio-economic positions than average. There is no evidence that bike sharing significantly reduces traffic congestion, carbon emissions and pollution. From a process perspective, bike sharing can be delivered through multiple governance models. A key challenge to operation is network rebalancing, while facilitating factors include partnership working and inclusive scheme promotion. The paper suggests directions for future research and concludes that high-quality monitoring impact/process data, systematically and consistently collected, as well as innovative and inclusive evaluation methods are needed.

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### 1. Introduction

This paper is concerned with identifying and critically interpreting the available evidence on bike sharing to date, on both impacts and processes of implementation and operation. The aim is twofold. First, the paper seeks to determine evidence gaps and limitations that need further investigation. Secondly, by drawing on the evidence review, it attempts to identify the enabling conditions for the occurrence and transferability of beneficial impacts and positive implementation and operation processes. By critically reviewing and reflecting on the available evidence on both impacts and processes, rather than on impacts alone as other existing reviews have done, this paper advances the current body of knowledge on bike sharing and contributes to the ongoing academic and policy discourse on this increasingly popular cycling measure.

Bike sharing involves the provision of a pool of bicycles across a network of strategically positioned 'bike sharing stations', typically distributed in an urban area, which can be accessed by different types of users (i.e., registered members or occasional/casual users) for short-term rentals allowing point-to-point journeys. Bike sharing is often named in different ways according to the geographical area of application, e.g., 'cycle hire' in the UK, 'public bicycle' in China and 'bicycle sharing' in North America (ITDP, 2013).

Bike sharing schemes (BSSs) have existed for almost fifty years but only in the last decade have they significantly grown in prevalence and popularity to include over 800 cities across the world and a global fleet exceeding 900,000 bicycles (Meddin, 2015). In their historical development BSSs have progressed through so-called 'generations' (see Beroud & Anaya, 2012 and DeMaio, 2009 for a detailed historical analysis). Modern 3rd generation BSSs share a few key features (Anaya & Castro, 2012; ITDP, 2013; OBIS, 2011; TDG & PBIC, 2012):

- The bicycles can be checked-in and out through the use of a personal 'smart card' using radio-frequency identification (RFID) technology, or a 'key'. Most modern systems are largely automated in this respect;
- Each bike sharing station, i.e., the station where bikes can be checked in and out of their docking points, can be equipped with terminals, also termed 'kiosks', where users can get information on the scheme, view the local and overall station network map, communicate with customer service, and in some cases make the payment for use;
- Wireless communication technology, e.g., general packet radio service (GPRS), allows real-time monitoring of occupancy rates at each station. If the bicycles are equipped with global positioning system (GPS), their movement through the network can be monitored.
- BSSs incentivise short-term rental hence maximise the number of times each bicycle is used, by allowing users to have, typically, the first 30 min free of charge (within their specific subscription for which they are charged upfront) and then increasing the charges

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rather substantially after that period. In this sense bike sharing is very different from a bike rental service: the former is about using the shared bikes to make short-term point-to-point journeys, the latter involves the renting, and private use, of a bicycle for a given amount of time. Users are generally required to provide credit or debit card details, which serve both as a deposit, as well as payment for registration and usage fees.

According to policy documents and various grey and academic literatures, BSSs are expected to contribute to a number of different objectives, including:

- To reduce single occupancy car journeys and ease traffic congestion;
- To reduce CO<sub>2</sub> emissions and to improve air quality by reducing other pollutant emissions from motorised traffic;
- To improve public health and increase levels of physical activity;
- To increase cycling levels, and help normalise and promote cycling (for example, by removing barriers associated with bike ownership, e.g., concerns about theft and parking);
- To improve accessibility and support flexible mobility, through enhanced transport choices and opportunities for multi-modality and inter-modality (for example, by acting as a 'first' or 'last mile' solution in connection with public transport);
- To improve road safety, in particular for cyclists;
- To enhance the image and liveability of cities and to support local economies and tourism.

The review of evidence provided here sheds light on whether, and to what extent, the aforementioned effects of bike sharing have been assessed, and with what results. The rest of the paper is organised as follows. **Section 2** provides a critical overview of the increasing number of information sources and growing body of knowledge about bike sharing, and explains the rationale for the evidence review on which the present paper is based. **Sections 3 and 4** summarise the evidence on users, usage and impacts of bike sharing, and discuss the results' significance and limitations. **Section 5** provides a summary of the evidence around managing the business of bike sharing from a process evaluation perspective, in particular in terms of drivers, barriers and lessons learnt. **Section 6** concludes the paper by discussing how the evidence presented here can be helpful in enhancing and transferring positive results in terms of impacts and processes of implementations to other contexts, and identifies key areas that merit further investigation.

## 2. Sources of information and evidence on bike sharing: an overview

Reflecting the rapid growth of bike sharing especially in the past ten years, a number of very different sources of information and evidence about bike sharing have appeared. These include:

- Guidelines and manuals for bike sharing operation, such as the handbook developed by the EU-funded OBIS project ([OBIS, 2011](#)) and two planning guides to bike share implementation, one focused on the U.S. context and experience ([TDG & PBIC, 2012](#)), and the second on the global experience to date ([ITDP, 2013](#)). Other important analyses of existing systems include an overview of Spanish BSSs by [Anaya and Castro \(2012\)](#), in Spanish but with a short summary of recommendations in English; and an analysis of BSS implementation and operation governance with particular attention to French and Spanish schemes ([Beroud & Anaya, 2012](#)). Relevant platforms for sharing results and good practice also comprise international conferences such as the European Cyclists' Federation's Velocity conferences and the European Transport Conference series.
- Websites, comprising both those offering general information on bike sharing and those set up by BSS operators and/or projects, which sometimes include scheme-specific data on operational/financial performance and customers' profile and satisfaction. Well-known

examples amongst the former category are: The Bike-sharing Blog,<sup>1</sup> Mobiped<sup>2</sup> and Suprageography<sup>3</sup> (in particular the Bike Sharing Map section) which keep track of all the BSSs across the globe and act as points of contact and reference for stakeholders involved in BSSs and, more broadly, anyone interested in this cycling measure. Amongst the BSS operators that make performance data and/or reports readily available in the public domain are: Capital Bikeshare<sup>4</sup>, Washington DC; Nice Ride Minnesota<sup>5</sup>; and Barclays Cycle Hire,<sup>6</sup> London. Other schemes may supply performance data and reports on request, including tender documents and contracts of operation.

- Reports and scholarly publications, including peer-reviewed journal articles, exploring one or more aspects and/or effects of bike sharing and focusing on one specific scheme or a range of schemes for which data are available. Most of these publications have appeared in the past five years, suggesting that this is still an emerging but potentially prolific area of research.

The review of evidence for this paper draws on a literature search aimed at identifying studies that met two requirements. First, these studies needed to provide some form of evaluation, assessment or appraisal of existing BSSs, involving the collection and/or generation of data on issues such as usage, impacts, and processes of implementation and operation. Second, the studies needed to be supported by well-explained and robust conceptual and methodological approaches.

The search was carried out by the author through a variety of scholarly databases and internet engines, and using a combination of keywords connected with bike sharing, evidence, impacts and evaluation (only documents in English were considered). Several considerations can be made in relation to the availability, relevance and significance of the range of the available evidence identified on this cycling measure.

First, it must be noted that although bike sharing has recently started to attract attention from commentators around the globe, including academic researchers, independent and peer-reviewed in-depth evaluations of existing schemes are not readily and publicly available. No single BSS (of a sufficient scale<sup>7</sup>) appears to have been fully and independently evaluated along an extensive range of impact and process dimensions (for an overview of different impact evaluation approaches, see [Hills & Junge, 2010](#); for process evaluation, see [Bloor & Wood, 2006](#)). More frequently, the existing studies look at one particular aspect or a set of characteristics of one or more schemes, with different methodological approaches. As a result, the available evidence is somehow patchy and does not easily lend itself to comparative analysis. However, the increasing availability of usage/performance data such as origin–destination journeys and station occupancy, often through explicit 'open data' policies, has stimulated the growth of academic literature on BSSs and has the potential to enable better comparative assessment of schemes ([O'Brien, Cheshire, & Batty, 2014](#)).

Secondly, the evidence available on bike sharing does not generally offer a clear understanding of the specific objectives that a particular scheme had sought to achieve. This makes it difficult to assess whether, and to what extent, a scheme has been 'successful'. This is particularly relevant when interpreting the results of academic studies of specific BSSs, which often reflect the authors' own research objectives and line of academic inquiry, rather than provide an evaluation of the scheme's success against its original objectives.

<sup>1</sup> <http://bike-sharing.blogspot.co.uk/>.

<sup>2</sup> [http://www.mobiped.com/vls\\_public-bicycles\\_bike-sharing\\_en.html](http://www.mobiped.com/vls_public-bicycles_bike-sharing_en.html).

<sup>3</sup> <http://oobrien.com/bikesharemap/>.

<sup>4</sup> <https://www.capitalbikeshare.com/>.

<sup>5</sup> <https://www.niceridemn.org/>.

<sup>6</sup> <http://www.tfl.gov.uk/info-for/open-data-users/our-feeds>. It must be noted that during the writing of this paper there was a change of sponsorship to the London scheme, which is now called 'Santander Cycles'.

<sup>7</sup> The author contributed to an in-depth impact and process evaluation of a bike sharing demonstration scheme in Bath, U.K., co-funded by the CIVITAS Plus Renaissance project, 2008–2012. The evaluation report is to be published by the European Commission.

The available evidence is relatively recent and generally refers to established schemes that have been operational for a whilst. Major schemes in North America (especially the U.S. and Canada) and Europe (the U.K., Ireland, Spain and France) appear to have attracted the most interest and scrutiny, followed by schemes in China (currently the largest in the world) and Australia.

The studies identified for the review include a variety of documents, with different methodological approaches and objectives. One is a review of the available evidence to date (Fishman, Washington, & Haworth, 2013), which helped identify original sources of evidence. The others involve the collection and analysis of operator data on users and usage characteristics, in a few cases with the use of models, and/or the generation of quantitative and qualitative data, through surveys conducted with users, non-users, operators, stakeholders and businesses, via self-completion and/or researcher-administered questionnaires.

The evidence presented in these studies concerns three main aspects of BSSs.

The first is about by whom, why and how BSSs are used, as this provides an understanding of how successful the schemes are in attracting customers, and thus generating cycling journeys and revenue. Evidence on how BSSs attract different typologies of users is also connected to issues around equity of access.

The second broad aspect is about the direct and indirect impacts associated with BSS implementation and use. These include change in travel attitudes and behaviours, effects on multi-modality and intermodality, and environmental, health and economic impacts.

Finally, the third aspect concerns issues around implementation and operation of BSSs, which however have attracted academic research scrutiny, in the form of quantitative and/or qualitative process evaluation, to a relatively lesser degree.

The evidence on these broad aspects of BSSs is thematically examined in the following three sections.

### 3. Evidence on users and usage of bike sharing

#### 3.1. Users' socio-economic profile and equity of access

In terms of users' socio-economic and demographic characteristics, there is now an established and broadly consistent body of evidence. Overall BSSs seem to attract a particular profile of user: male, white, employed and, compared to the average population in which BSSs are implemented, younger, more affluent, more educated and more likely to be already engaged in cycling independently of bike sharing (Fishman, Washington, & Haworth, 2014a; Shaheen, Martin et al., 2012; Shaheen, Martin et al., 2014).

According to a study of Dublinbikes, Dublin (Ireland), users are predominantly male (78%), young (58.8% are between the ages of 25–36) and on higher incomes (57.3% of respondents earn a salary of more than €40,000) than the resident population (Murphy & Usher, 2015). In London, real usage data revealed that women account for less than 20% of total bike sharing trips (Goodman & Cheshire, 2014) and that under 45 s account for an estimated 78% of all bike sharing travel time (Woodcock, Tainio, Cheshire, O'Brien, & Goodman, 2014). Similarly, a 2013 online survey of BSS members in five North American cities (Montreal, Toronto, Salt Lake City, Minneapolis-Saint Paul, and Mexico City) revealed that, overall, the dominant age category was the 25–34 year old demographic and most members were of Caucasian ethnicity (Shaheen et al., 2014).

In Beijing, Shanghai and Hangzhou, bike sharing users were found to have a higher level of car ownership than non-users, which seems to be something unique to the Chinese context (reviewed by Fishman et al., 2013).

Overall, evidence on users' average profile suggests that bike sharing largely reproduces unequal patterns of participation associated more in general with cycling, reflecting gender, class and ethnic differences in

cycling practices found in countries with low cycling levels (Steinbach, Green, Datta, & Edwards, 2011).

Although lack of a debit/credit card has been highlighted as a barrier to a more equitable use of BSSs by several scholars (Goodman & Cheshire, 2014; Murphy & Usher, 2015), other more fundamental factors are likely to be at play in shaping the skewed composition of bike sharing user base.

One of these factors concerns the scheme's geographical coverage. A study of bike sharing in Lyon, France, for example, highlighted the uneven spatial distribution of Vélo's stations, with the offer concentrated in socio-economically active areas, near multimodal transport interchange hubs and universities. Vélo's rapid success in attracting customers, therefore, appears linked to the socio-demographic characteristics of the people resident or working in such areas, i.e., students, qualified professionals and one-person households. Nevertheless, the relative affordability of the annual membership (€15 in 2011) combined with public transport integration, spatially and through the pricing policy, are also relevant to understand the scheme's success in generating cycling journeys.

The importance of BSS geographical coverage and price in shaping the profile of users is also acknowledged by the only two studies, amongst those identified by this review, which specifically focus on equity of access. Both use Barclays Cycle Hire (BCH) in London, U.K., as a case study (Goodman & Cheshire, 2014; Ogilvie & Goodman, 2012).

Overall, this evidence indicates that residents in less affluent areas can and do use bike sharing systems if these are made available in their local areas. In fact, Ogilvie and Goodman (2012) found that trip rates amongst registered users were higher amongst residents in poorer areas after adjusting for the fact that these poorer areas were less likely to be near a BCH docking station.

Using actual BCH usage data over three years, Goodman and Cheshire (2014) investigated whether and to what extent the scheme is contributing to the Mayor of London's policy aim of encouraging cycling amongst a broad variety of Londoners, from different gender and socio-economic backgrounds. The research took into account: the geographic extension of the BCH to East London in March 2012, with the inclusion of more deprived areas; and the doubling of BCH prices in January 2013. Overall, the evidence shows that the scheme did become more equitable over time, with the introduction of casual use which encouraged women to use the scheme, and with the eastern extension which increased the share of trips made by residents of poorer areas. However it also found that women and residents from poorer areas remained under-represented, partly reflecting BCH use by affluent, male commuters from within and outside London. The proportion of trips made by users from poorer areas increased from 2.9% to 4.3% across the study period, from July 2010 to July 2013. The doubling of BCH prices however appears to have partially offset these positive outcomes, with an overall decline in casual use observed after the price increase that may have disproportionately occurred amongst users living in poorer areas.

Although a comparative study of equity of access across all existing systems is not readily available, the geographical location of bike sharing stations can be plausibly regarded as a key explanatory factor to the socio-economic profile of the scheme's users. Incidentally, station location is mentioned as an important aspect underpinning overall scheme profitability in qualitative surveys of BSS stakeholders (Shaheen et al., 2012, 2014, discussed in Section 4.8) and in most bike sharing information sources, such as those listed in Section 2. There is also evidence that some of the most recent systems, such as City Bike in New York City,<sup>8</sup> have used the experience of other more established schemes to position stations in strategic locations (e.g., areas with intense cultural, social and economic activity) to maximise use. It is not surprising, then, that the resulting bike sharing offer may disproportionately favour a particular socio-economic profile, when such profile is concentrated precisely in the areas usually targeted by BSSs.

### 3.2. Determinants of and barriers to bike sharing use

Evidence on the barriers and determinants of bike sharing use appears to be growing but there are limitations in the range of case studies examined and methodologies used.

According to user surveys conducted in different cities and countries, bike sharing can improve the experience, accessibility and affordability of personal travel, through greater transport choice, reduced journey times and reduced mobility costs. In short, the evidence suggests that "convenience" in its broadest meaning consistently emerges as the key motivating factor for bike sharing use. This has been found by a number of studies looking at BSSs in North America, China and Australia (Fishman et al., 2013; Shaheen et al., 2014) and other cities, as follows.

A survey of active users of the London BCH scheme showed that the main reasons for joining were "health/fitness", "speed" and "convenience" (Transport for London, 2015).

"Travel time savings" were mentioned as a reason to use Capital Bikeshare (CaBi), Washington DC, by 73% of users, followed by "enjoyment" (42%), "exercise" (41%) and "travel cost savings" (25%). Joining to save money had a significant positive association with new trips, indicating that bike sharing can help meet suppressed demand for travel and make urban travel more affordable (Buehler & Hamre, 2014).

Similarly, bike sharing was perceived as cost saving by a sample of Valencia University students, who also considered it effective to address bicycle security/theft concerns (Molina-García, Castillo, Queralt, & Sallis, 2013). Avoidance of private bike theft and maintenance was also mentioned as a motivation to use BIXI in Montreal (Bachand-Marleau, Lee, & El-Geneidy, 2012).

Barriers to joining and using bike sharing systems have been explored to a lesser extent and predominantly in an Australian context.

A qualitative study of cyclists, including BSS users, and non-cyclists in Brisbane identified the following reasons for the relatively low usage of CityCycle, the local BSS: mandatory helmet legislation, overnight closure, barriers to instant access, lack of cycle infrastructure and road safety concerns, which are also a major barrier to cycling in general (Fishman, Washington, & Haworth, 2012). The study found that mandatory helmets were negatively perceived by both users and operators. Moreover, BSS users tended not to use a helmet and considered them an inconvenience and barrier to spontaneous journeys. However, when helmets were provided with the bike, usage was shown to increase. A further quantitative study of bike sharing use in Australian cities (Fishman, Washington, Haworth, & Mazzei, 2014b) found that inconvenience compared to other motorised transport and distance from home, work or other key destinations were key barriers to join and use the BSSs.

In terms of factors that increase the likelihood of bike sharing use, proximity of residence to docking stations appears to be strongly correlated with use, as well as socio-economic characteristics and travel behaviours.

Two independent survey-based studies of Montreal residents, including users and non-users of BIXI, showed that people living within 250 m of a docking station were over twice as likely to become users of the bike sharing system as those living further away (Fuller et al., 2011), and those living within 500 m of a docking station were three times as likely (Bachand-Marleau et al., 2012).

Additionally, Fuller et al. (2011) reported that being aged 18–24 years, being university educated and using cycling as the primary mode of transport to work correlated with bike sharing use. This resonates with other findings on users' profile reported in Section 3.1.

The survey conducted by Bachand-Marleau et al. (2012) revealed that different factors were at play in influencing a. the likelihood and b. the frequency of using BIXI. In particular, spatial factors and travel

habits appeared to determine likelihood, whilst users personal preferences, such as annual membership, aversion to bike maintenance and positive opinion about BIXI bike design, correlated more with frequency of use.

Similarly, a before-after survey-based study of a sample of Valencia University students (Molina-García et al., 2013), examining change in cycling behaviour including use of the Valenbisi BSS, found that those most likely to become users were students who had one or more stations within 250 m of home, were already contemplating to start cycling and perceived fewer infrastructural and safety barriers to active commuting.

### 3.3. Usage characteristics: bike sharing rates, patterns and purpose of use

In terms of usage rates, Fishman et al. (2013) found discrepancies in the evidence provided by different sources on the same scheme. Overall, reported usage rates vary from 3–8 trips per day per bike, and these have been found to increase significantly in conjunction with disruptions to the public transport systems. Some schemes, such as BCH in London and Capital Bikeshare (CaBi) in the Washington DC area, reported high usage levels, with each bike producing on average 3 trips per day (Fishman et al., 2014a). BCH was launched in July 2010, currently comprises over 10,000 bicycles across 100 km<sup>2</sup> at more than 750 locations, and has generated over 32 million cycling trips to date (Transport for London, 2014). CaBi opened in September 2010, with over 2500 bicycles at more than 300 stations (Buehler & Hamre, 2014). Other schemes are comparably less used thus less successful in attracting customers, e.g., in Australia with 0.3–0.4 trips per day per bike (Fishman et al., 2013).

Several studies have addressed usage patterns and their characterisation focusing on different BSSs. This area of research, which is attracting growing academic interest, is likely to be fuelled by the increased availability of large datasets on BSS users, bicycles and stations on one side, and the parallel enhancement of visual analytic and data mining techniques on the other. These can achieve enhanced results by processing and overlaying data from multiple sources, for example by linking spatio-temporal bicycle movement data to the data of the BSS users responsible for them. These combined advances have significantly expanded the research opportunities on bike sharing and have the potential to significantly contribute to scheme planning, operation, monitoring and evaluation.

Applying data mining techniques to a large dataset from the London scheme, Lathia, Ahmed, and Capra (2012) found that a change to the BCH access policy in December 2010, which allowed 'casual' users access the scheme for spontaneous journeys without the need to register for an annual membership, affected the system's usage patterns throughout the city but with great spatio-temporal variations. Whilst generally reinforcing week-day commuting trends, the policy change also generated greater weekend usage and determined a complete reversal of usage in a number of stations. This implies that different types of users, in this case annual members and more occasional users, can have distinctive preferences and patterns of use.

Varied usage patterns can also become apparent within the same user category, e.g., annual members, with gender emerging as a key variable. Vogel et al. (2014) developed a segmentation of Vélo'v users according to the intensity and regularity of their bike sharing behaviours, ranging from 'users of heart' to 'sporadic users', which echoes more general typologies of cyclists. Significant in these findings was the distinctively gendered characterisation of the resulting user typologies, with the intensity of cycling practice strongly linked to being male.

Using a large smart-card-based dataset from Nanjing, China, Zhao, Wang, and Deng (in press) were able to detect significant gender and temporal variations in bike sharing travel time and trip chain patterns. Women in particular were more likely to make multiple-circle bike sharing trip chains (i.e., with multiple destinations but same start and

<sup>8</sup> [http://www.nyc.gov/html/dcp/pdf/transportation/bike\\_share\\_part5.pdf](http://www.nyc.gov/html/dcp/pdf/transportation/bike_share_part5.pdf).

end point) than men, especially on week days. This is consistent with more general gender differences in travel patterns, which see women undertake more complex trip chaining to carry out household and childcare related tasks.

Gender and temporal variables also emerged as important dimensions in a study of group-cycling (i.e., journeys made by two or more users together in space and time) using data from the London BCH (Beecham & Wood, 2014a). The research found that group-cycling fitted a general and expected pattern associated with discretionary activities, with group journeys more likely to occur at weekends, late evenings and lunchtimes; generally taking place within more pleasant parts of the city; and between individuals apparently known to each other. With respect to gender, female cyclists were found to be more likely to make late evening journeys when cycling in groups and women were very significantly overrepresented amongst so-called 'first time group cyclists', i.e., users for whom the very first BCH journey was a group journey.

Studying the spatio-temporal context under which bike sharing journeys are made on the London scheme, another study by the same authors (Beecham & Wood, 2014b) found that women's journeys were highly spatially structured. Even for utilitarian cycle trips, routes involving large, multi-lane roads were comparatively rare, with female users preferentially selecting areas of the city associated with slower traffic and more segregated cycle routes.

A study using real usage data from BIXI, Montreal, combined with a general statistical modelling technique (Faghih-Imani, Eluru, El-Geneidy, Rabbat, & Haq, 2014) identified the following key correlates to bicycle flows: weather conditions, with users more likely to bike-share under good weather conditions; time of day/week; during the weekends the bicycle usage reduced, however Friday and Saturday nights were positively correlated to arrival and departure rates; the provision of cycle infrastructure, with bicycle flows and usage of the BSS increasing with cycle lanes/patterns nearby a BIXI station; and the characteristics of the built environment around the stations, with bicycle flows decreasing further away from the core business district. Accessibility indicators appeared to be correlated to bicycle usage for every BIXI station. Restaurants, other commercial enterprises and universities in the vicinity of a station significantly influenced the arrival and departure rates of the BIXI station. Population density and job density around bike sharing stations appeared to influence demand and usage rates at different times of the day/week.

The BIXI system variables, i.e., number of stations and capacity, were shown to have a complex relationship with arrivals and departures. The model found that reallocating capacity by adding a further BIXI station had a stronger impact on bicycle flows compared to increasing one station's capacity. This means that dense bike sharing station networks may have a beneficial effect on usage levels. Increasingly sophisticated techniques are being developed to estimate the optimal location and capacity of stations, for example using GIS-based models (García-Palomares, Gutiérrez, & Latorre, 2012).

As in the BIXI study, the importance of cycling infrastructure in supporting bike sharing journeys is also reported in a study of CaBi, Washington DC, which showed a significant relationship between bike share activity and the presence of bike lanes (reviewed by Fishman et al., 2013).

Combining usage data with members' residence data, Ogilvie and Goodman (2012) found that proximity of residence to bike sharing stations significantly increased frequency of use of the London BCH scheme. This contrasts with the evidence provided by Bachand-Marleau et al. (2012), which identified users' personal preferences as a key determinant of frequency of use, but this is likely to be due to the different BSS under study and methodology/data used.

Work-related purposes dominate bike sharing use, as the available evidence on journey purpose suggests. However, the prevalence of different purposes may be influenced by gender and temporal variables, such as time of the day and day of the week.

Commuting was the most common purpose found in a survey-based study of four North American schemes in 2011/12, namely Washington DC, Minneapolis-Saint Paul, Montreal and Toronto (Shaheen et al., 2012).

Similarly, work-related purposes (commuting and travel on employer's business) dominate the use of Barclays Cycle Hire in London (Transport for London, 2014). Moreover, according to Beecham and Wood (2014b), purpose of use of the London BCH is highly gendered. Usage amongst men was found to be highly regular, suggesting a strong commuter function, whilst recreational journeys over weekends and within London parks appeared to be more dominant for female members.

Trip purpose profiles in Dublin were found to be different between am peak (7:30–10:00) and pm off-peak (19:00–21:30), with commuting dominating peak times (85.3%) and non-work purposes more prevalent in non-peak times, chiefly leisure (48.3%). No significant difference was found between the income levels and age profile of users during the peak and off-peak times (Murphy & Usher, 2015).

#### 4. Evidence on the impacts of bike sharing

##### 4.1. Transport mode substitution

This area of impacts has received comparably more attention and there are now several studies looking at this issue across different BSSs. Fishman et al. (2013) report that the ability of bike sharing to attract trips previously made by private vehicles remains a key challenge, with the available evidence exposing relatively low mode substitution rates and suggesting that bike sharing is predominantly used instead of walking and public transport.

For example, although Dublinbikes users reported considerable behavioural change, the prevailing trend showed a large modal shift (80.2%) from sustainable modes of travel to the bicycle, particularly from walking (45.6%) and including transfer from bus (25.8%) and rail (8.8%). The scheme was much less successful at achieving modal shift from the private car (19.8%) which was attributed to the relatively compact space in which the scheme operates. Statistical analysis showed that modal shift amongst higher income earners was most likely to be from car to bicycle or from rail to bicycle, whilst for lower income groups modal shift to the bicycle was more likely to occur from bus to bicycle or from walking to the bicycle (Murphy & Usher, 2015).

Similarly, findings from a variety of user surveys suggest that modal shift from the private car occurs only for a minority of bike sharing users. Amongst European examples are:

- London BCH, UK – 2% of car trips substituted for (Fishman et al., 2014a);
- Vélo'v, Lyon, France – 7% (Fishman et al., 2013);
- Bicing, Barcelona, Spain – 9.6% (Rojas-Rueda et al., 2011).

Examples outside Europe include:

- BIXI Montreal, Canada – 2% (Bachand-Marleau et al., 2012);
- Capital Bikeshare, Washington DC, US – 7%
- Nice Ride Minnesota in the twin cities of Minneapolis-Saint Paul, US – 19.3%
- Melbourne Bike Share, Australia – 19%
- CityCycle Brisbane, Australia 21% (all reported in Fishman et al., 2013, 2014a).

On their own, however, these mode substitution results do not offer detailed information on the magnitude of further impacts, such as on traffic levels and public health, including that of the users. This is because other important data are needed, notably the frequency of car journeys substituted for, their previous duration and route, which are

not normally collected. Specific data on newly generated journeys, i.e., not previously made at all, including their purpose and frequency, are important to capture the broader benefits of bike sharing on the overall well-being of users. However, this type of information is not always and consistently collected in scheme users' surveys.

#### 4.2. Broader changes in users' travel behaviours

In addition to mode substitution effects, bike sharing has been found to influence and change the wider travel behaviour of users, but with differing results in different contexts and in respect of different transport modes.

With respect to cycling, bike sharing appears to increase the frequency in which a bicycle (personal or shared) is used, thus contributing to promote cycling behaviour and increase overall cycling levels. As BSS users don't generally use helmets or other dedicated cycling clothing, bike sharing can potentially normalise the image of cycling (Goodman, Green, & Woodcock, 2014).

A before-after study examining whether exposure to Montreal's BIXI scheme was associated with an increase in total cycling, including cycling on BIXI and personal bicycles, and accounting for both utility and leisure cycling, found that BIXI led to greater likelihood of cycling amongst people living in areas where shared bicycles were made available. In particular, a greater likelihood of cycling was observed for those exposed to the BSS after the second season of implementation whilst controlling for weather, built environment, and individual variables (Fuller et al., 2013).

A recent survey of active users of the London BSS showed that 78% reported starting to cycle or cycling more as a result of the scheme (Transport for London, 2015).

Eight months after scheme implementation, 19% of the sampled Valencia University students had become BSS users; cycling as the main mode of transport to university had increased from 7 to 11%; and the proportion of participants engaged in cycling increased by 14.6%. There was no change in behaviour for students who had always access to car/motorbike, lived further than 5 km from the university and had no bike sharing stations within 250 m from home (Molina-García et al., 2013).

The Dublin scheme was reported to promote the use of the bicycle as a transport mode beyond bike sharing and encourage users to purchase a bike. 68.4% of sampled users claimed not to have cycled for their current trip prior to the launch of Dublinbikes, and 63.4% who own their own private bicycle said they purchased it as a result of using the scheme (Murphy & Usher, 2015).

Most BSS users surveyed in 2011/12 in four North American cities (Shaheen et al., 2012) reported an increase in their cycling levels (72% cycling more, 22% the same, 5% less) as a result of bike sharing. Similar results were found by a 2013 survey of BSS members in five North American cities (Montreal, Toronto, Salt Lake City, Minneapolis-Saint Paul, and Mexico City) (Shaheen et al., 2014).

Considering changes in car driving, the available evidence suggests that bike sharing can reduce car use. Across the four North American schemes surveyed by Shaheen et al. (2012), 40% of users overall reduced car use, with the remaining 60% reporting no change. In their most recent study, Shaheen et al. (2014) found that the share of respondents who reported driving less as a result of bike sharing ranged from 29% in Montreal and 35% in Toronto to over 50% in Mexico City, Minneapolis-Saint Paul, and Salt Lake City. It is worth noting that the share of members who did not drive prior to joining the bike sharing scheme varied greatly across the cities, from 8% in Salt Lake City to 51% in Montreal.

Evidence on behaviour change in walking and use of public transport modes as a result of bike sharing is more mixed and appears to depend upon the particular scheme attributes, transport infrastructure, built environment and population characteristics/travel patterns/preferences in the cities implementing the schemes.

The study by Shaheen et al. (2012) found the following modal shifts across the four North American schemes: bus (56% no change, 38% reduced use, 7% increased use), rail (48%, 43%, 9%), walking (43%, 34%, 23%).

In their second study, Shaheen et al. (2014) found similar results overall but also different patterns of behavioural change across the sampled cities. Most members in the North American cities surveyed either reduced their use of the bus or did not change their behaviour, except in Salt Lake City. Rail usage increased as a result of bike sharing in Minneapolis-Saint Paul and Salt Lake City. In contrast, a decrease in rail usage was found in both Canadian cities and Mexico City, justified by the larger population size and denser rail networks. Across all cities surveyed, the main reasons for using the bus/rail less were reduced cost and faster travel offered by bike sharing and, for bus users, a desire to get exercise. The most common response to increasing bus/rail use due to bike sharing was better access both to and from a bus/rail line. The evidence around walking behaviour change was more mixed in this study, with only Mexico City respondents markedly increasing their walking levels as a result of bike sharing. By overlaying actual usage data of Nice Ride Minnesota for 2013 to the survey data, the study found that those respondents shifting away the most from any modes tended to use bike sharing with greater frequency.

The main weakness of this body of evidence on travel behaviour change is the lack of reliable quantitative data on the extent, in terms of frequency and magnitude, of the change in overall motorised travel on one hand and active travel on the other. As a result, the available evidence on travel behaviour outcomes cannot currently be used to robustly determine direct and indirect impacts, for example on public health and the environment.

The reviewed studies offer a number of possible explanations for the different patterns of behaviour change across different BSSs. For example, Fishman et al. (2013) suggested that BSS users in cities with relatively high car modal share exhibited a higher car mode substitution rate than BSS users in cities with an already low car modal share. However, robust statistical analysis of data from existing schemes is needed to check whether this observation can be supported.

Other contextual factors identified as possible reasons for differential patterns of change in relation to public transport use include the quality, level of service and patronage of the available public transport options (Shaheen et al., 2014). To shed light on these issues, Martin and Shaheen (2014) further interrogated the users' survey datasets obtained in two North American cities (Washington DC and Minneapolis) by mapping geocoded home and work locations of respondents. Behavioural shifts away from public transport in response to bike sharing were found to be most prominent in core urban environments characterised by high population density, whilst shifts towards public transport were most common in lower density areas on the urban periphery. The authors suggest that, for those users living in areas with less available/frequent public transport options, bike sharing can generate public transport journeys by acting as a first or last mile connection.

#### 4.3. Effects on and synergies with public transport use

Bike sharing can, at the same time, connect to and substitute for public transport. The exact outcome of this combination is the result of a complex interrelationship amongst various factors, such as the characteristics of the scheme, its users and the location where it is implemented, including public transport infrastructure attributes and population travel behaviours and preferences. An increasing number of studies have started to link together data on all the above factors to better understand the patterns of bike share and public transport interaction.

An analysis of bike sharing usage in Melbourne, revealed that the number of trips was significantly higher for docking stations located in areas with relatively less accessible public transit opportunities, suggesting that the BSS was potentially substituting for public transport rather than connecting to it (Fishman et al., 2014b).

This contrasts with evidence from other cities such as London (Goodman & Cheshire, 2014), Washington DC and Paris (Shaheen et al., 2014), where bike sharing usage was significantly higher in correspondence to rail stations (London and Washington DC) and Metro stations (Paris). The direction of the bicycle flows is a key variable in this respect. For example, statistical and visual analytic techniques applied to the BSS in Nanjing, China, allowed Zhao et al. (in press) to ascertain that rail stations attracted bike sharing trips the most, whilst docking stations in residential areas produced outward bike sharing trips the most.

In London, Goodman and Cheshire (2014) found the BCH to be relatively popular with non-Londoners from commuter towns with a cycling culture such as Oxford and Cambridge, suggesting that strategic marketing of a BSS in rail-connected commuter towns with an existing cycling culture could potentially increase participation and support bike-rail integration. It must be noted here that women were found to be particularly under-represented in this group of non-resident commuters (Beecham & Wood, 2014b).

In Dublin, a sizable minority of BSS users (39%) reported using the scheme in conjunction with another mode to complete their trip, primarily public transport: 56.3% rail and 35.2% bus. Overall the scheme appears to support cycle-only journeys starting and ending in the central area, however it also helps users to connect to rail and bus, which are reported to be largely segregated within the wider Dublin transport network (Murphy & Usher, 2015).

Similarly, evidence on BIXI in Montreal (Bachand-Marleau et al., 2012) suggests that the scheme supports single journeys (for 57% of survey respondents) as well as inter-connected journeys, in particular those combining bike sharing with metro (30%). Bike–bus integration was less prevalent (12%).

#### 4.4. Impacts on attitudes to cyclists

The impact of BSSs on attitudes to cyclists has received very little attention to date thus evidence is particularly limited. The study of Dublinbikes reported that bike sharing can contribute towards raising awareness and acceptance of cyclists, and increasing road safety for cyclists. Over 80% of survey respondents were also car drivers. Of these, 93.8% said that using the Dublinbikes scheme had raised their awareness of cyclists on the road whilst driving (Murphy & Usher, 2015). Fishman et al. (2012) found that BSS users in Brisbane perceived better behaviour from motorists when riding the shared bikes than when cycling with their own bikes.

#### 4.5. Environmental impacts

Many commentators and publications supportive of bike sharing provide estimates of the CO<sub>2</sub> emission savings resulting from bike share use to suggest positive environmental impacts. However the significance of these results is questionable because such estimates are not normally substantiated with robust evidence from usage data and/or user surveys, but rest on the invalid assumption that all bike sharing journeys substitute for car journeys.

One study, amongst the ones reviewed, attempted to conduct a more realistic, indirect, assessment of the environmental impacts of bike sharing. Using data from BSSs in London (UK), Melbourne and Brisbane (Australia), Washington DC and Minnesota in the U.S., Fishman et al. (2014a) examined the net changes to motor vehicle use as a consequence of bike sharing, by looking at substitution rates for car modal share but, crucially, also accounting for the impact of any motor vehicles used for bike re-distribution (also called re-balancing) and maintenance. Re-distribution of bicycles is necessary to correct any imbalance in the number of available bikes and free docking points across the network.

The findings suggest that bike sharing can increase rather than reduce overall motor vehicle usage, when the effect of bike maintenance

and re-distribution is accounted for. The single factor that mostly affected overall motor vehicle use in this study was rate of car substitution.

More in detail, bike sharing reduced the overall distance travelled by motor vehicle except in London, where for each km saved there were 2.2 km generated by the re-distribution fleet, with associated negative environmental impacts. The study estimated that if car substitution rate in London was 10% (instead of 2%), then the overall impact would be reversed. Looking at all the cities combined, the impact was negative, as London accounted for most of the redistribution fleet's travelled kilometres. This study suggests that BSSs can be successful in reducing motorised vehicle use but this depends on the combined effect of members' usage of the scheme and the scheme's redistribution fleet and maintenance operations.

A key limitation of this study relates to the inability to include the contribution of casual users, who have been shown to have a different pattern of use than those of members (Lathia et al., 2012).

No evidence on life-cycle analysis of bike sharing compared with other measures or scenarios has been identified.

#### 4.6. Health impacts

Health impacts from bike sharing have recently started to attract attention and a few studies are now available, which collectively suggest that bike sharing can have health benefits. However the different methodological approaches used do not allow for reliable comparative assessments.

A before–after study of BIXI, Montreal, found increased cycling levels amongst those who lived in proximity of docking stations, suggesting that BSSs can lead to increased cycling thus indirectly promoting public health. However, this study does not indicate whether, and to what extent, the increase in cycling levels is accompanied by a decrease in other forms of physical activity, such as walking, as a result of bike share use (Fuller et al., 2013).

Commuting by Valenbisi was found to provide about half the recommended weekly physical activity (150 min) and a small reduction in the students' Body Mass Index (BMI) was reported. These results suggest that BSSs can have a positive role in the promotion of healthy weight, potentially preventing 2 kg/academic year of weight gain (Molina-García et al., 2013). Similarly, a survey of Capital Bikeshare users found that, of over 3100 responses, 31.5% reported reduced stress, and about 30% indicated they lost weight as a result of using the scheme (Shaheen et al., 2014). However, the study of Dublinbikes reported that health benefits to users were likely to be minimal given the significant modal shift from walking (Murphy & Usher, 2015).

Positive health benefits from bike sharing have been reported by two health impact studies using different modelling techniques, data and assumptions.

The most recent, based on actual data from the London BCH, measured the change in lifelong disability adjusted life years based on one year impacts on incidence of disease and injury, modelled through medium term changes in physical activity, road traffic injuries, and exposure to air pollution. Overall the research estimated a positive health impact, but not currently accruing equally to the different social groups using the scheme (Woodcock et al., 2014). The benefits were clearer for men than for women, because of higher cycle injury rates for females, and for older users than for younger users. A limitation of this study is that it only modelled health benefits from short-medium term behaviour change, without accounting for the possibility that cycling at a particular age increases cycling across the life course, or otherwise affects disease incidence at older ages. According to the authors, reliable data on such long term effects are limited and their omission in the model may have underestimated the lifetime health benefits to those who start cycling at young ages.

The other health impact study, using Bicing in Barcelona as a case study (Rojas-Rueda, de Nazelle, Tainio, & Nieuwenhuijsen, 2011), estimated 69.2 deaths averted per million users per year, significantly

higher than the results obtained by the London study, which generated estimates of 3.3 to 10.9. This is due to the different schemes and cities under consideration, models used and assumptions made.

#### 4.7. Economic impacts on users and local businesses

Only two studies seeking to quantify the local economic impacts of bike sharing have been identified. This arguably limited evidence is however consistent and suggests that bike sharing can generate economic benefits at the neighbourhood level and contribute to enhancing local economies. The magnitude of such benefits, and associated level of confidence, is however limited. Other types of economic benefits, such as on employment and to the stakeholders involved in BSS delivery and operation, have not been considered by the reviewed studies.

Buehler and Hamre (2014) investigated potential economic benefits of CaBi, Washington DC, at the neighbourhood level through a survey of users and businesses proximate to bike sharing stations. Only a minority of surveyed users (23%) reported spending more money because they used CaBi. Statistical analysis found that income level was positively associated with new trips, spending levels, and spending during new trips. The literatures reviewed by this study suggest that cycling and bike sharing are associated with consumer spending and some induced travel and that cycling facilities can attract customers to nearby businesses. The business survey showed that whilst 70% identified a positive impact of BSS on the neighbourhood, only 20% reported a positive direct impact of bike sharing on sales. In addition, 61% would have either a positive or neutral reaction to replacing car parking in front of their business with a bike sharing station but were less favourable towards converting the sidewalk. These attitudes, the authors suggest, may depend on the characteristics of the area. In Washington DC, possibly because of traffic congestion and relatively extensive public transport, businesses may be more used to non-driving customers and would agree with converting part of the parking spaces to bike sharing spaces. Businesses that perceived a positive impact on sales from the BSS were more likely to support the expansion of the system and the replacement of car parking with bike sharing stations.

The other study, by Schoner, Harrison, and Wang (2012) and looking at Nice Ride Minnesota, also found positive economic impacts and estimated that BSSs can generate additional economic activity in the proximity of bike stations. An average of US\$1.29 per week was reported, which would equate to US\$29,000 over the season April to November.

Limitations of both studies include survey administration at a particular time of the year, which affects the results obtained, and the fact that both the user and business surveys collected estimated spending information based on subjective assessments and perceptions, rather than actual monetary transactions.

As discussed earlier in Section 3.2, bike sharing can further benefit users by reducing both transport costs and travel time. Whilst the former type of benefit has not been assessed quantitatively, a few studies have tried to estimate the latter, which has relevant economic implications.

Using actual usage data on bike sharing journeys, including duration and distance, Jensen, Rouquier, Ovtracht, and Robardet (2010) found that most journeys on the Lyon scheme were shorter than a trip by car and calculated a 13% reduction in travel time compared to using a car for the same journey. In their study of the health impacts of the London BCH, Woodcock et al. (2014) estimated a 20% average time saving for trips made using the shared bikes as opposed to the alternative modes used previously. Although these estimates for time saving have not been translated into monetary benefits by the respective studies, a report by Transport for London (2014) provides a calculation of these and other benefits as part of a broader economic appraisal of the London BCH. This is discussed in the following section.

#### 4.8. Financial viability and wider economic benefits

An important area of 'success' emerging from various guides to bike sharing implementation is the ability of BSSs to generate revenue, hence

reducing the amount of public funding or other subsidies and sponsorships necessary to run these schemes. According to the specific BSS governance model, local governments can support bike sharing directly with a subsidy or indirectly by allowing operators to advertise on the bicycles, stations or other public spaces. Overall, the readily available evidence on the financial viability of existing bike sharing systems is limited and predominantly anecdotal or qualitative in nature. This may be due to the commercial sensitivity of such information and the specific BSS contractual arrangements. Only one quantitative economic appraisal has been identified amongst the publicly available literature (Transport for London, 2014).

Interviews with North American scheme operators (Shaheen et al., 2012, 2014) found that membership fees, usage fees, and sponsorships account for the vast majority of operating income. Additionally, four key factors impacting profitability were identified: the location of bike sharing stations, in particular near tourist attractions and public transport, and in mixed-use areas; the ability to retain registered members, e.g., annual members; providing a range of discounts; and, finally, the ability to find new revenue sources. The interviewed operators also stressed that whilst securing a strong core of annual members was important to success, tailoring the system to encourage occasional/casual use was imperative for a system's long-term economic viability, especially in lieu of public subsidy.

A recent economic appraisal of the Barclays Cycle Hire by Transport for London (2014) found a Benefit-To-Cost Ratio (BCR) of 0.7:1 based on outturn costs, revenues and benefits realised to date plus forecasts up to 2017/18. The monetised benefits realised to 2013/14 accounted for £55.3 m of the expected total of £129.4 m to 2017/18 and included: journey time savings of £26 m (£61.2 m expected overall to 2017/18); health benefits of £22.5 m (£70 m overall); ambience benefits of £7.4 m (£20.6 m overall). Ambience benefits include the provision of way-finding at stations, the value of a new bicycle and maintained bicycle, improvements in bicycle and docking point availability and the value of CCTV and lighting at docking stations. The total cost of the scheme to date is £133 m, including both capital and operating costs.

In purely economic terms, the results of this appraisal look unfavourable (O'Brien, 2015). However, these results reflect the assumptions made in selecting and attributing monetary values to the benefits of bike sharing. An important question arises: since standard economic appraisal techniques have been developed, and hence are more suitable, for evaluating large transport infrastructure projects, how can they adequately capture the 'value' of bike sharing interventions for a variety of beneficiaries, and especially given the current limited range and depth of the evidence around bike sharing benefits? This issue is discussed in the concluding section of the paper in relation to developing evaluation frameworks that are suitable for bike sharing.

### 5. Evidence on the process of bike sharing implementation and operation

Only two studies (Shaheen et al., 2012, 2014) appear to have systematically collected and analysed the views of BSS operators and stakeholders to understand the 'process' of bike sharing implementation and operation, such as drivers, barriers and lessons learnt. However, these studies concern only the North American context. Other commentaries and analyses of bike sharing, such as those listed in Section 2, provide recommendations based on the collective knowledge and practical experience of the authors. Importantly in this discussion of processes, Beroud and Anaya (2012) offer a detailed analysis of the different models of BSS governance according to the specific roles played by the public and private sectors in scheme promotion, equipment provision and scheme operation. The particular governance arrangement, including the specific and legally-binding service contracts between the parties involved, is crucial to understand the financial, regulatory, organisational and legal contexts within which each scheme operates. In turn, knowledge of these contexts is essential to understand how BSSs can evolve and be improved,

and crucially how more systematic and consistent monitoring data collection/generation could be achieved.

In-depth process evaluations of existing schemes, using robust methodologies to survey all the involved stakeholders and taking into account the different governance models, are needed to improve knowledge of what works, and under what circumstances, in delivering and operating BSSs.

Most importantly, the available 'process evidence' suggests that bike sharing is dependent upon political, policy and public support to sustainable travel and cycling in particular. Positive cycling culture, growing cycling levels and pro-cycling policy measures, such as the provision of quality cycle infrastructure, have all been identified as important complementary factors that can sustain bike sharing during and after implementation.

The London scheme, for example, was conceived and implemented in the broader context of the Mayor's Transport Strategy, the Mayor's 'Cycling Revolution' and effectively contributes to deliver the Mayor's Vision for Cycling in London (Transport for London, 2014).

Moreover, this and other successful schemes, such as Dublinbikes in Ireland and Bixi in Montreal, were implemented alongside improvements in the cycling infrastructure and in the context of sustained positive cycling trends (Fuller et al., 2013; Murphy & Usher, 2015).

According to the stakeholders' survey conducted by Shaheen et al. (2012, 2014), challenges to delivery and operation include bicycle redistribution, which can be a complex and costly task to organise; addressing negative perceptions of cycling as unsafe and, in certain cultures (e.g., Mexico City), associated with being poor; mandatory helmet legislation; insurance and other legal issues. Vandalism and theft were both reported to negligible, as were bike sharing accident rates (4.3 accidents per year for schemes with over 1000 bikes are reported).

Drivers, i.e., facilitating factors, include: establishing partnerships within local government and with community stakeholders; marketing and public outreach prior to and after launch, e.g., by engaging the public through public fora and online-based 'suggest-a-station' platforms; locating bike sharing stations through appropriate spatial analysis to support system use; employing mobile station technology that can be easily relocated according to usage patterns; the use of advanced technologies to track bicycles, understand user behaviour, deter bike theft and support system management, for example through pay-as-you-go services; and facilitating membership portability and interoperability.

Similar recommendations are provided by Transport for London (2014), in particular around the value of enhanced partnership working with London Boroughs; the adoption of appropriate project management tools to control costs and improve scheme delivery; detailed launch management; accounting for customer feedback; adopting a system software with enhanced asset management, automated job scheduling capabilities and improved billing and customer self-service processes.

Amongst the challenges experienced in the delivery, operation and evaluation of the Barclays Cycle Hire, Transport for London (2014) highlights the lack of performance benchmarks specifically for bike sharing at the time of scheme implementation, and the need for improved bike sharing modelling/appraisal techniques and tools.

## 6. Discussion and conclusion

This review has found that the overall evidence on the impacts, and especially on the benefits, of bike sharing is growing but is still limited in terms of the range of case studies available, the methods used, the data collected and/or generated, and the range of characteristics and impacts that have been examined. Further research is needed to allow for systematic comparative analysis of schemes and to increase the level of confidence associated with the results.

Similarly, this review has found a very limited range of robust evidence on the 'process' of setting up and operating BSSs. In-depth process evaluations, using robust methodologies to survey all the involved stakeholders, are needed to improve knowledge of what

processes work and under what circumstances, including the role of the specific governance model. Such process evaluations would also advance knowledge of the characteristics that support or hinder the continuing 'success' of a scheme. Crucially, evidence on whether schemes are successful according to their original objectives is also lacking.

In what follows, key results in terms of impact and process evidence are summarised and used to make recommendations for both urban sustainable mobility policy and academic inquiry. In terms of policy, some of the available evidence is helpful to understand how particular beneficial impacts, or positive implementation and operation processes, could be replicated or optimised in other locations wishing to introduce bike sharing. In terms of academic inquiry, the strengths and limitations of the reviewed evidence can be used to sketch a future research agenda for evaluation, by suggesting possible directions concerning topics of investigation, data to be used and research methods.

Perhaps the most significant consideration to be drawn from the all reviewed evidence, on impacts and processes, is that bike sharing benefits from, and is dependent upon, clear political, policy and public support to sustainable mobility and cycling in particular. The development of a positive cycling culture, growing cycling levels and pro-cycling policy measures, such as the provision of quality cycle infrastructure, have all been identified as important complementary, and in some cases determining, factors that can sustain bike sharing during and after implementation. Process evidence also identified partnership working and continuing involvement of stakeholders and local communities as facilitators to bike sharing implementation.

Bike sharing, in turn, has the potential to further promote the image and the practice of cycling, through increasing cycling levels and contributing to normalise cycling, as some of the evidence shows. Further investigation that would enhance this area of evidence includes studying the effects of bike sharing on the wider population, through a survey addressing perceptions of the schemes and attitudes to cycling and cyclists, which would improve understanding of whether and to what extent BSSs can act as catalysts for private bike riding and help normalise cycling as a transport mode.

Obviously, the potential to promote the image and the practice of cycling can only be realised if BSSs generate a considerable amount of cycling journeys and become highly visible in the areas where they are implemented. In other words, achieving high usage rates and a large user base are often used as the metrics to judge, as a rule of thumb, whether BSSs are effective and successful. This is also linked to the ability of schemes to generate revenue.

Some of the evidence on impacts (e.g., studies of BIXI and Vélo'v) and processes (e.g., on North American schemes) reviewed here suggests that such goals can be achieved by establishing bike sharing as a dense network in areas with intense social, cultural, leisure and economic activities, and in connection with public transport networks. Meanwhile, the increasing availability and quality of detailed data at the level of the user, bicycle and station, coupled with the ongoing development of sophisticated data mining, visualisation and processing techniques, are dramatically enhancing the ability to understand what factors contribute to boost usage rates and membership levels. Over-reliance on these factors as principal indicators of success, however, can lead to neglect other important aspects.

Achieving success in terms of cycle journey generation, for example, does not guarantee that BSSs are also socially inclusive. An established and broadly consistent body of evidence suggests that bike sharing tends to attract a particular profile of user: male, white, employed and, compared to the average population, younger, more affluent, more educated and more likely to be already engaged in cycling independently of bike sharing.

If promoters and operators of BSSs wish to achieve equity of access, then schemes need to be made available, accessible, affordable and attractive to a variety of social groups and types of users (e.g., registered members and occasional users). For example, by developing special

pricing policies/discounts for low-income or other target groups, as well as providing multiple types of cycles suitable for different uses.

More fundamentally however, bike sharing systems cannot become more socially inclusive if they are persistently designed and marketed to appeal to the sensibilities and interests of particular types of users, and made available predominantly in areas where such types of users happen to live, work or visit. Although systems can evolve to cover more disadvantaged areas, as the London scheme has done, it remains problematic to reconcile the need to demonstrate financial and usage success on one hand, and social inclusivity on the other. Nevertheless, showing a commitment to be more inclusive may also help BSS promoters and operators secure wider public support and more convincingly justify the resources needed to fund such schemes. This paper argues that an open debate on these issues would be helpful.

The results on BSS average user profile and associated access inequalities help identify a key area where more research is needed. This concerns the perceptions, attitudes and preferences of the social groups that are currently under-represented amongst bike sharing users, such as those who are able to ride a bicycle but do not cycle, ethnic minorities, disadvantaged social groups, women and older people. Methods that could be employed to address these gaps include quantitative and qualitative surveys, as well as more participatory types of research, conducted with users and non-users belonging to under-represented categories. This could be especially useful in locations where bike sharing is viewed as a 'public service' and equity of access is regarded as an important objective. Furthermore, the evidence on enabling factors to bike sharing operation suggests that effective and ongoing public engagement, including challenging negative perceptions of cycling, may help attract and maintain a diverse range of users.

Whilst arguably a valuable goal in its own right, making bike sharing more socially inclusive can also have an important function: it can contribute to a more equitable distribution of the key positive outcomes identified by this review. These comprise in particular health benefits, improved travel experience, enhanced accessibility through greater and more sustainable transport choice, reduced journey times and increased affordability of personal travel through reduced mobility costs. Health benefits in particular can be enhanced by improving road safety for cyclists, so that cycling injury rates are reduced.

According to personal preferences and needs, bike sharing enables users, individually or in groups, to undertake a variety of social, economic and leisure activities, where commuting constitutes an important but not exclusive component. Drawing on this evidence, further research could explore, through in-depth surveys of different typologies of users, how BSSs enhance users' capabilities to access life-chances, and affect their overall quality of life and well-being. This would allow building a more complete and articulated picture of the multiple benefits of bike sharing at the level of the individual and for different categories of users, including under-represented ones, which in turn could be used to develop better assessments of the 'value' and 'success' of BSSs.

There is currently no evidence suggesting that bike sharing produces significant reductions in urban congestion levels and CO<sub>2</sub> emissions, or improvements in air quality, at least in the short-medium term. The available evidence on mode substitution is established and consistent: rather than substituting for car journeys, bike sharing is predominantly used instead of walking and public transport. Moreover, when the effect of using motorised fleets for bike maintenance and re-distribution is accounted for, bike sharing can increase rather than reduce overall motor vehicle usage and emissions, with associated negative environmental and air quality impacts. Re-balancing the bike network has also been identified as a key operational challenge.

This has important research and policy implications. Deploying low or zero emission re-distribution vehicles could be one possible solution to improve the environmental credentials and impact of BSSs, for example through policy mechanisms providing incentives to operators to do so. However, more sophisticated and potentially fully-automated techniques could be developed. Further research could involve, for example,

the development of a system of incentives and/or dynamic pricing to users based on real-time assessment of the re-balancing needs of the network, combined with real-time data on users' needs and preferences, collected through mobile media. As a result, BSSs might become more self-rebalancing and need less external intervention.

Evidence on broader travel behaviour change as a result of bike sharing is mixed and varies according to the specific context of implementation and in respect of different transport modes. Overall, cycling behaviour is shown to increase whilst driving to decrease, albeit for a smaller proportion of users. However, whilst cycling levels may increase as a result of bike sharing, the potential displacement of physical activity through walking should be borne in mind when supporting the introduction of bike sharing on public health grounds.

Future research could develop better frameworks to map out and evaluate the effects of bike sharing on users' travel behaviour, for example by using innovative research methods combining detailed users' travel behaviour history and patterns as a result of bike sharing, socio-demographic data and actual bicycle movements.

Bike sharing can, at the same time, connect to and substitute for public transport for different types of trips and users. The exact outcome of this combination is the result of a complex interrelationship amongst various factors, such as scheme attributes, user preferences and the characteristics of the area of implementation, including travel patterns, public transport infrastructure and level of service.

Research is needed to further explore how these multiple factors play out in different contexts and take into account the specific bike sharing governance model on one side, and the regulatory framework underpinning public transport ownership/operation on the other. This in turn has a significant policy implication, connected to the possibility of using bike sharing to help manage public transport demand, for example reducing overcrowding on some services, promoting use of others or helping integrate different public transport modes. An improved understanding of the mutual synergies between bike sharing and public transport, in different governance settings and regulatory frameworks, could also contribute to better assess the differential outcomes of this interaction for BSS users, public transport users, transport operators, local authorities and the wider population as a whole. This area of investigation relies on the availability of performance data on different public transport modes.

Bike sharing can generate economic benefits to users, through reduced travel time and costs, and contribute to enhancing local economies, by connecting people to employment, retail and other places where economic activity takes place. However the evidence is very limited and the magnitude of such benefits appears to be modest. Further research addressing economic impacts is necessary, along with research exploring wider impacts of BSSs on urban liveability, city image and tourism, through surveys of residents, businesses and visitors.

Evidence on broader economic benefits including financial viability and profitability issues is also very limited, with the only economic appraisal available, based on the London scheme, reporting an unfavourable 'value for money'.

Two considerations can be made on this issue. First, the suitability of standard economic assessments commonly used to evaluate large transport infrastructure projects is questionable, especially given the limited range and significance of the evidence currently available on bike sharing. Parallel to extending and improving the evidence base, further research is necessary to develop innovative evaluation frameworks and methods that are specific to bike sharing, able capture their full range of impacts and not just those which are directly and more easily quantifiable. Multi-criteria analysis could be a useful starting point.

Secondly, it is essential that bike sharing evaluations begin from identifying the objectives that a scheme seeks to achieve, through an in-depth consultation of all the stakeholders, rather than undertake generic assessments without a clear operational, and agreed upon, definition of 'success'. In the London case, for example, the improved equity of access following the Eastern extension, and the consequent more equitable

distribution of positive outcomes, were not explicitly included amongst the expected monetary benefits in the overall appraisal. In explaining the background to the scheme, however, widening participation in cycling was mentioned as a key policy goal (Transport for London, 2014).

Developing assessment tools, identifying objectives and determining metrics for evaluating bike sharing 'success' raise questions about whose voices, values and interests should be included in these decisions. Following Banister (2008), this paper argues that realising sustainable mobility in practice requires a 'paradigm shift' in decision-making processes, with more open and active involvement of society as a whole.

A final reflection concerns the data that is needed to support the various strands of inquiry, suggested in this paper, to achieve better evaluation of bike sharing impacts and processes. As mentioned earlier, remarkable progress is being made towards better monitoring data as well as more sophisticated computer-based data visualisation and processing techniques. Further evaluation and robust comparative assessments of schemes are therefore dependent upon the future availability and quality of a wide range of monitoring BSS data, but also on financial, performance and process-type indicators, which should be systematically and consistently collected across different schemes. Presumably, the specific bike sharing governance model and contractual arrangements might dictate the range and quality of data that can be released in the short-term. Nevertheless, a commitment to better, consistent and transparent monitoring and evaluation is necessary if bike sharing is to be considered an effective element of sustainable urban mobility strategies.

## Acknowledgements

The review of evidence undertaken for this paper was supported by the author's involvement in the evaluation of the CIVITAS Plus Renaissance project in Bath (2008-12) and the ongoing EVIDENCE project (2014-17), both financially supported by the European Commission. The author wishes to thank two anonymous reviewers, whose insightful comments and helpful suggestions significantly contributed to improve this paper.

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