Transport Reviews

ISSN: 0144-1647 (Print) 1464-5327 (Online) Journal homepage: http://www.tandfonline.com/loi/ttrv20

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Elliot Fishman

To cite this article: Elliot Fishman (2016) Bikeshare: A Review of Recent Literature, Transport Reviews, 36:1, 92-113, DOI: 10.1080/01441647.2015.1033036

To link to this article: http://dx.doi.org/10.1080/01441647.2015.1033036

Published online: 24 Apr 2015.

Transport Reviews, 2016
Vol. 36, No. 1, 92–113, http://dx.doi.org/10.1080/01441647.2015.1033036

Bikeshare: A Review of Recent Literature

ELLIOT FISHMAN[§]

Department of Human Geography and Spatial Planning, Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, Room 404, PO Box 80115, 3508 TC Utrecht, The Netherlands

(*Received 12 November 2014; revised 18 March 2015; accepted 19 March 2015*)

ABSTRACT *The number of cities offering bikeshare has increased rapidly, from just a handful in the late 1990s to over 800 currently. This paper provides a review of recent bikeshare literature. Several themes have begun to emerge from studies examining bikeshare. Convenience is the major motivator for bikeshare use. Financial savings has been found to motivate those on a low income and the distance one lives from a docking station is an important predictor for bikeshare membership. In a range of countries, it has been found that just under 50% of bikeshare members use the system less than once a month. Men use bikeshare more than women, but the imbalance is not as dramatic as private bike riding (at least in low cycling countries). Commuting is the most common trip purpose for annual members. Users are less likely than private cyclists to wear helmets, but in countries with mandatory helmet legislation, usage levels have suffered. Bikeshare users appear less likely to be injured than private bike riders. Future directions include integration with e-bikes, GPS (global positioning system), dockless systems and improved public transport integration. Greater research is required to quantify the impacts of bikeshare, in terms of mode choice, emissions, congestion and health.*

1. Introduction

Bikeshare has grown rapidly in the past decade. Although the concept has been around since the 1960s, the number of cities offering bikeshare has increased from just a handful in the late 1990s to over 800 at the time of publication (Meddin & DeMaio, 2015). Contemporary bikeshare programmes (BSPs) refer to the provision of bikes, which can be picked up and dropped off at self-serving docking stations. Typically, trips are of a short duration (less than 30 min). The bicycles usually contain technologies that allow the programme operator to track their docking station location and some are equipped with a global positioning system (GPS) (Davis, 2014). Payment is usually by credit card, and this also acts as a form of security and eliminates the anonymity that led to the demise of earlier, less technologically advanced BSPs (DeMaio, 2009; Shaheen, Guzman, & Zhang, 2010).

The global growth of BSPs has spurred an enthusiastic response from transport researchers, which has led to a burgeoning of papers examining bikeshare. Who

[§]Current address: Institute for Sensible Transport, 3 Nicholson Street, East Brunswick, Melbourne, VIC 3057, Australia. Email: info@sensibletransport.org.au

uses bikeshare and why? What factors prevent others from choosing bikeshare and what might encourage them to do so? What impact has bikeshare had on reducing car use? What do the data tell us about bikeshare and road safety? This paper sets out to capture critical themes emerging from recently published literature on these and other bikeshare topics. The overall aim is to provide researchers, bikeshare operators and government policy-makers with a distillation of the salient findings from bikeshare research. It is hoped such a paper will enhance the capacity of the rapidly growing bikeshare sector to capitalise on recent research, thereby enhancing the performance of new and existing BSPs.

1.1. *Review of the Literature*

This review of the English language bikeshare literature encompasses recent research from North America, Asia, Europe and Australia. The emphasis is on papers published since 2013, as earlier papers of relevance are included in a synthesis of bikeshare literature published by this journal (Fishman, Washington, & Haworth, 2013). Relevant papers were collected via a scan of Scopus and Google Scholar databases, using the search terms 'Bicycle sharing', 'Bikeshare', 'Public bicycle' and 'Public bike', conducted between May and October 2014. As the following section shows, bikeshare activity is strongest in China, but there is a relative paucity of bikeshare research in Asia and this review reflects this imbalance.

This paper reviews research across a range of bikeshare topics, including its documented history and growth, usage patterns, user preferences and demographics. Research examining barriers to bikeshare are also reviewed, as well as the little research that has taken placing assessing the impacts of bikeshare. Fleet rebalancing research is touched upon, followed by a synthesis of future directions for the bikeshare industry and critical gaps in knowledge and priorities for researchers. The review highlights current limitations in bikeshare knowledge, and these are particularly evident in the areas of rebalancing, sampling of non-bikeshare users and the impacts on bikeshare. These issues are especially important given that a central motive for the development of bikeshare is sustainable transport outcomes, yet no standard methodology has been established to enable operators and researchers to accurately and consistently measure the impact BSPs have on car use, climate change, congestion or public health. Finally, some researchers have taken the opportunity provided by automated bikeshare data collection to analyse temporal and spatial relationships and this is not captured in the current review. Rather, coverage of this work is included in a separate paper in this *Special Issue*.

1.2. *Policy Context*

Many cities during the post-Second World War period became increasingly dependent on the private automobile (Fishman & Brennan, 2010). An increasing recognition of the negative impacts of car use has emerged over recent years, in terms of congestion, air and noise pollution, safety, climate change and reductions in physical activity. This has spurred a growing interest in urban cycling generally (Fishman, 2014; Handy, van Wee, & Kroesen, 2014). It is this policy context, combined with increasingly affordable payment and tracking technologies, that has provided the platform for the extraordinary growth of bikeshare.

2. History and Recent Growth

In 1965 Witte Fietsen (White Bikes) was launched in Amsterdam (Davis, 2014). This programme consisted of white painted bicycles on the street, free for people to use. The total absence of security mechanisms led to theft and vandalism, and a rapid demise of Witte Fietsen (DeMaio, 2009). Bikeshare, as a concept, experienced little growth after the failure of the White Bike programme, until technological advancements emerged designed to reduce the threat of vandalism and theft.

2.1. *Generations of Bikeshare*

Some researchers have categorised the evolution of bikeshare systems into four 'generations' (Parkes, Marsden, Shaheen, & Cohen, 2013). The White Bike programme described above is known as a first-generation bikeshare 'system', characterised by no payment or security functions. Second-generation programmes involved a coin deposit system (similar to trolleys at a supermarket or airport). The first large-scale second-generation programme launched in Copenhagen in 1995, but the anonymity exposed the system to theft (DeMaio, 2009). The problems experienced by these first two generations of bikeshare led to the development of third-generation systems, which are characterised by dedicated docking stations (in which bicycles are picked up and returned), as well as automated credit card payment and other technologies to allow the tracking of the bicycles (Shaheen, Cohen, & Martin, 2013). It is these elements, in combination with growing public policy interest in cycling (Pucher & Buehler, 2012), that have enabled the rapid growth of BSPs globally (Shaheen & Guzman, 2011). The features of fourth-generation systems are not quite so clear, but are said to potentially include dockless systems, easier installation, power assistance and transit smartcard integration (Parkes et al., 2013).

2.2. *Bikeshare's Recent Growth*

In the past decade, the number of cities operating a BSP has increased from 13 in 2004 to 855 as of 2014, as illustrated in Figure 1. The global bikeshare fleet is estimated at 946 000 bicycles, of which 750 500 are in China (Meddin & DeMaio, 2015). China also has more than double the number of bikeshare systems as the next closest country, at 237, compared to 114 in Italy and 113 in Spain. The USA, a relative latecomer to bikeshare, has 54 cities offering bikeshare (Meddin & DeMaio, 2015).

In 2010, Oliver O'Brien began visualising bikeshare activity in different cities, making this available via the website http://oobrien.com/bikesharemap/. This became the most efficient method of examining the number of bikes available and the number of bikes in use. Interestingly, an analysis of these data reveals that the number of bikes available is often considerably lower than what bikeshare operators report. Figure 2 uses data collected via the aforementioned bikeshare map for selected cities, showing the maximum number of observed bicycles. European systems tend to be larger than North American systems and some have suggested that this may be due to a tendency for European systems to be totally or largely funded through advertising, as well as cycling participation being higher in most European countries (Parkes et al., 2013).

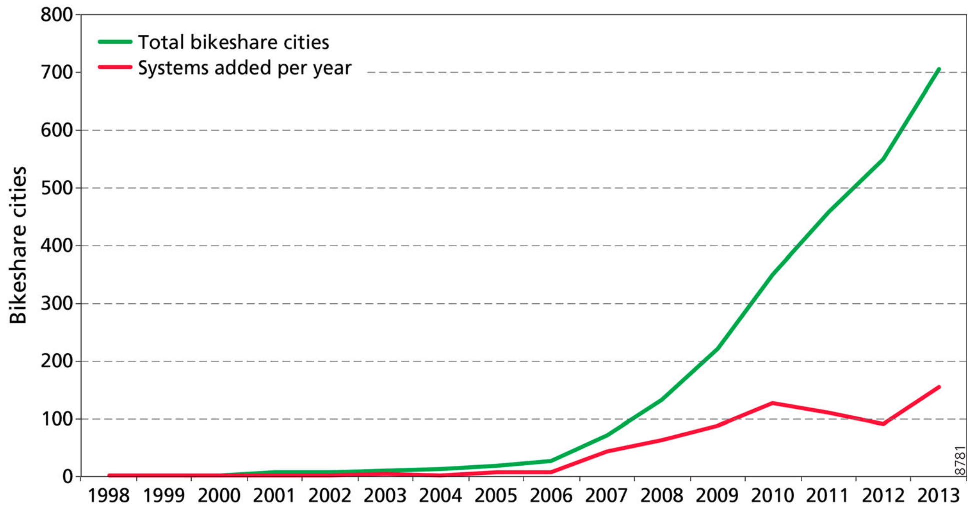

Figure 1. Growth in bikeshare cities (1998–2013).
Source: Meddin (2014)

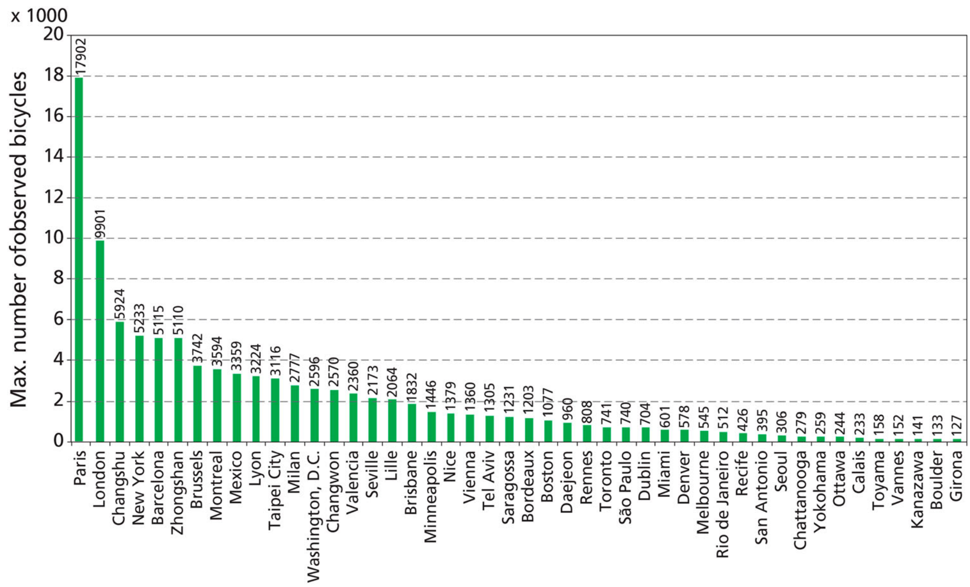

Figure 2. Size of bikeshare, selected cities.
Note: Not all cities with bikeshare are included. Changshu figure is October 2012 and Changwon and Ottawa figures are October 2013. *Source*: O'Brien (2014)

3. Bikeshare Usage and User Preferences

3.1. *Comparing Different BSPs*

Bikeshare usage can vary dramatically between BSPs in different cities, but they generally exhibit a similar daily usage profile. Weekday usage peaks between 7 am–9 am and 4 pm–6 pm, while weekend usage is strongest in the middle of the day (e.g. see Pfrommer, Warrington, Schildbach, & Morari, 2013), as might

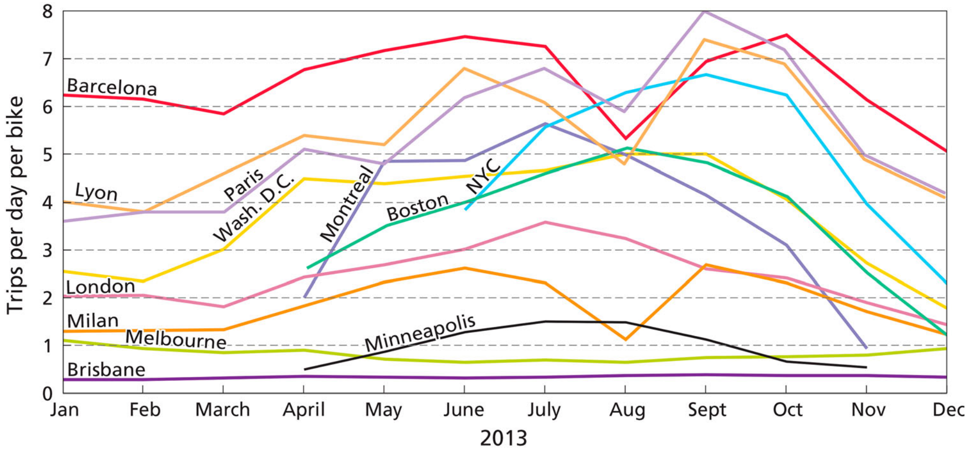

Figure 3. Bikeshare usage, trips per day, per bike, 2013.
Note: Montreal and Minneapolis, owning to their harsh winters, are closed during the coldest months of the year.

be expected. In comparing system usage between different cities, it has become standard to use the metric *trips per day per bike*, as this controls for variation in the number of bikes in a system. Figure 3 illustrates trips per day per bike for several prominent BSPs for which the author was able to obtain the necessary data. It shows considerable differences in usage, both with the same system at different times of the year, as well as between systems. BSPs are busier in the warmer months, which generally confirms the relationship between weather and propensity to cycle found in research on private bike riding (e.g. Ahmed, Rose, & Jacob, 2010). Of the cities included in Figure 3, Barcelona is the most heavily used across the year, with New York City's *Citi Bike* achieving a remarkable four trips per day per bike in its first full month (May 2013), and almost doubling by September. Paris has the highest peak, reaching eight trips per day per bike in September. Washington, D.C., consistently reached four to five trips per day per bike in summer and even in their sometimes icy winters have at least twice the usage of Australian BSPs during their busiest months (January/February). Melbourne and Brisbane have around 0.8 and 0.3 trips per day per bike.

Unlike private bicycle riding, it is relatively easy to determine the trip duration of bikeshare journeys, as each trip is generally time stamped at the point a bicycle is removed from a docking station and again when it is returned. A study on bikeshare trip duration, using data from Melbourne, Brisbane, Washington, D.C., Minnesota and London found they fell within a tight band of between 16 and 22 min (Fishman, Washington, & Haworth, 2014a). Other researchers have found casual users typically take longer trips than annual members (Buck et al., 2013) and duration has also been shown to vary seasonably, with longer trips during warmer months (Zaltz Austwick, O'Brien, Strano, & Viana, 2013).

Third generation, IT-based BSPs offer researchers unprecedented access to large-scale ridership data. Readers interested in bikeshare usage that takes a spatial approach, particularly through the use of large data sets provided by bikeshare operators, are encouraged to read *Big Data and Cycling* provided as a separate paper as part of this Special Issue of *Transport Reviews*. A Special Issue of the *Journal of Transport Geography* dedicated to bikeshare research offers additional insights into spatial examinations of bikeshare (e.g. Corcoran & Li, 2014; Corcoran, Li, Rohde, Charles-Edwards, & Mateo-Babiano, 2014; Faghih-Imani, Eluru, El-Geneidy, Rabbat, & Haq, 2014; Goodman & Cheshire, 2014; Vogel et al., 2014). These works as well as future research capitalising on GPS embedded in new BSP hardware offer promising opportunities to examine geospatial and temporal bikeshare usage patterns, potentially providing new insights into route choice and other usage characteristics.

3.2. *User Preferences*

The motivations and preferences for using bikeshare is an area of interest to researchers, policy-makers as well as BSP operators. As many BSPs require those signing up for a monthly or annual membership to provide an email address, operators have been able to gauge the views of members with relative ease, via emailed online surveys. This section provides a review of literature regarding the results of these activities.

Convenience is the major perceived benefit identified by bikeshare users (Fishman et al., 2013). *Capital Bikeshare* in Washington, D.C. conduct regular surveys of their members. In 2013 some 11 100 members (50% of total membership) were emailed a survey (response rate 34%). The main benefit identified by respondents was enhanced convenience provided by bikeshare (LDA Consulting, 2013). Specifically, some 69% of respondents noted *get around more easily, faster, shorter* as 'very important' in their motivation for bikeshare use. This finding is consistent with earlier studies of this programme (LDA Consulting, 2012), as well as similar surveys of bikeshare users in London (Transport for London, 2014), and a multi-system North American survey (Shaheen et al., 2013). Research on Australia's two BSPs (*Melbourne Bike Share* and *CityCycle*) also found that convenience is the main motivating factor (Fishman, Washington, Haworth, & Mazzei, 2014). Figure 4 provides an illustration of motivating factors for bikeshare sign up, as provided by existing *CityCycle* and *Melbourne Bike Share* annual members. As noted earlier, *convenience* is the predominant motivation, with proximity between work and closest docking station identified as the second strongest motivator (which could also be argued falls under the convenience theme). Other research has shown the important of docking station proximity to *home*. For instance, Bachand-Marleau, Lee, and El-Geneidy (2012) found Montreal respondents living within 500 m of a docking station were 3.2 times more likely to have used bikeshare. One possible explanation for why this did not emerge

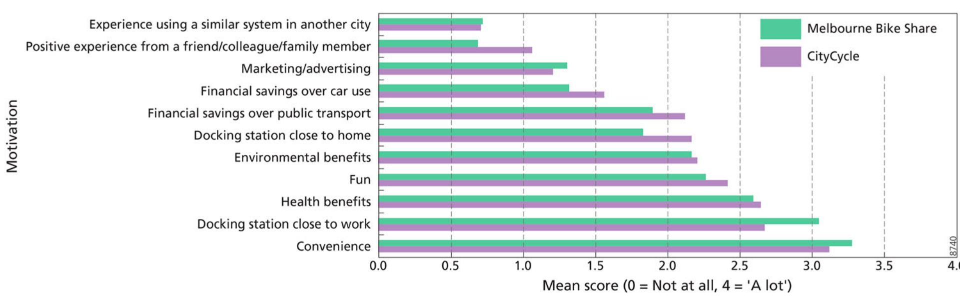

Figure 4. What motivated you to become a *CityCycle/Melbourne Bike Share* member?
Source: Fishman et al. (2014)

from the Australian research is that the docking station catchment is overwhelmingly located in employment rather than residential districts (Fishman et al., 2014).

Saving money has also been found to be a motivating factor for members of some BSPs (though a weak motivation in Figure 4). For low income members of *Capital Bikeshare*, over 70% of respondents note *saving money on transport* is an important sign-up motivation (LDA Consulting, 2013). In a related finding from a London study, bikeshare members who were residents of poorer areas had higher trip rates than members of more affluent suburbs (Ogilvie & Goodman, 2012). One possible reason why financial savings did not feature as a strong motivation for Australian BSP members may be because they had a vastly higher income than the general population (Fishman, Washington, Haworth, & Watson, 2015).

3.2.1. *User frequency*. One of the somewhat surprising findings from investigations on BSP user frequency is that, on the whole, members are not particularly frequent bikeshare users. In London, almost half (49%) of members responding to a Transport for London survey reported not having used the service once in the past month (Transport for London, 2014). In Washington, D.C., some 21% female *Capital Bikeshare* members reported no rides in a typical month, compared to 13% for men (Buck et al., 2013). In an Australian study, almost half (46%) of annual members recorded no trips in the previous month and only 14% use the system everyday (Fishman et al., 2014).

Based on the above data, it appears that many bikeshare subscribers may view bikeshare as an occasional adjunct to their primary and secondary transport modes. In focus group discussions with bikeshare members, a commonly reported motivation for signing up was a desire to show support for the government decision to initiate a BSP (Fishman, Washington, & Haworth, 2012a) and this may help explain why around half of members report no usage in the previous month.

3.2.2. *Trip purpose*. The most common trip purpose for bikeshare appears to be somewhat dependent on the type of user. For instance, a survey of *Capital Bikeshare* users in Washington, D.C. which reveals 43% of long-term members last trip was work related, whereas this drops to 2% for short-term users (Buck et al., 2013). Similarly, in London, 52% of respondents of an annual member survey report that their last trip was commuting to/from work, with no other trip purpose accounting for more than 10% (Transport for London, 2014). The day the survey was taken is not identified and this may influence results, as a weekend survey distribution is likely to show higher levels of social trips. In Brisbane, 65% of *CityCycle* casual users report that their main trip purpose for their last *CityCycle* journey was 'leisure or sightseeing', whereas for long-term subscribers, only 14% recorded this as the purpose of their last trip. Long-term users are much more likely to report using *CityCycle* for work trips (Roy Morgan Research, 2013). Among the most detailed description of bikeshare trip purpose, LDA Consulting (2013) identified that trip purpose can vary by residential location, age, gender, ethnicity and whether the member has a car available for their use. Women were found to be more likely to report making errands by bikeshare, whereas men were more likely to report commute trips by bikeshare (LDA Consulting, 2013).

3.2.3. *Voluntary helmet use and bikeshare*. A consistent theme emerging from the literature on bikeshare and helmets is that in jurisdictions in which helmet use is voluntary, bikeshare users are less likely to wear a helmet than a private bike rider in the same city. For instance, an observational study has found US bikeshare riders are four times less likely to wear a helmet than private bike riders in the same cities, controlling for age and gender (Fischer et al., 2012). In London, 16% of bikeshare riders wear helmets, compared to 64% for those on private bikes (Goodman, Green, & Woodcock, 2014). A recent study in New York City found some 85% *Citi Bike* users do not wear a helmet (Basch, Zagnit, Rajan, Ethan, & Basch, 2014) and 45% of *Capital Bikeshare* surveyed members report *never* wearing a helmet (LDA Consulting, 2013). Interestingly, helmet use appears to vary considerably depending on whether the bikeshare user is a long-term or short-term subscriber. For instance, in a study by Buck et al. (2013), 94% of short-term subscribers did not wear a helmet, compared to 63% for long-term subscribers. An explanation for this difference might be that short-term subscribers may be more likely to take spontaneous trips, in which they did not have a helmet with them. Previous research has revealed a reluctance to carry a helmet on the chance they will use bikeshare spontaneously at some point during the day (Fishman et al., 2012a).

3.2.4. *Demographics of bikeshare users*. The demographics of bikeshare users have become a common focus of attention for bikeshare operators and researchers. The issues examined include gender and income mix relative to the underlying population averages, as well as ethnicity and education status. Much of this research has revealed common trends; users tend to be of higher average income (e.g. Fishman et al., 2015; Lewis, 2011; Woodcock, Tainio, Cheshire, O'Brien, & Goodman, 2014), and education status (e.g. Fishman et al., 2014; LDA Consulting, 2013; Shaheen et al., 2013) and engaged in full-time or part-time work (Woodcock et al., 2014).

Buck et al. (2013) carried out one of the few studies that set out to specifically examine demographic differences between bikeshare users and other cyclists. The authors collected data on *Capital Bikeshare* users (short- and long-term subscribers) as well as regular cyclists in the same geographic area (Washington, D.C.). The authors found that in comparison to regular bicycle riders, bikeshare users were more likely to be female, younger and own fewer cars and bicycles. *Capital Bikeshare* users were likely to have lower mean household incomes compared to regular cyclists (US$81 920 compared to US$93 180). Interestingly, however, and something not reported in the Buck et al. study, median household income for the general population in the Washington, D.C. area is US$64 267 (United States Census Bureau, 2013). This suggests both bikeshare users and general bicycle riders have higher incomes than the general Washington, D.C. population, though it is possible response bias contributes to this difference. A study by Goodman and Cheshire (2014) found that users of the London BSP were disproportionately wealthy when the programme began in 2010. As the programme matured, however, the proportion of users from deprived areas increased from 6% to 12% between 2010 and 2013. The increase in usage fees in January 2013, however, has, according to Goodman and Cheshire (2014) resulted in a reduction in the level of *casual* use from those residing in the most economically deprived areas of London.

The ethnicity of bikeshare users has been documented in some North American programmes as well as in London. The results show some substantial differences between bikeshare users and the general population. For instance, only 3% of *Capital Bikeshare* members are African-American, compared to 8% for general bicycle riders in the D.C. area (Buck et al., 2013), despite African-Americans making up some 50% of the Washington, D.C. population (United States Census Bureau, 2013). Members of London's BSP have been found to differ demographically from the general London population. Some 88% of respondents to a Transport for London identified as being white (Transport for London, 2014), compared to 55% for the general London population (Office of National Statistics, 2014). Many BSPs do not cover the full residential area of the city, and this may offer an explanation for the demographic biases of bikeshare users.

In terms of bicycle ownership, Buck et al. (2013) found only 29% of *Capital Bikeshare* members owned a bicycle, compared to 94% for general bicycle riders. A study using snowballing sampling in Montreal, Canada, found those owning a bike were less frequent users of bikeshare (Bachand-Marleau et al., 2012). Interestingly, the same study found those possessing a driver's licence had 1.5 times greater odds of using bikeshare.

Several studies have identified a relationship between gender and bikeshare usage. One US commentator has suggested bikeshare does not have the same level of gender disparity as general cycling in North America (Goodyear, 2013), although no report details were offered allowing the reader to verify the numbers provided in the online piece. In countries with low levels of general cycling, such as the UK, the USA and Australia, between 65% and 90% of cycling trips are by men (Pucher & Buehler, 2012), while in strong cycling countries such as the Netherlands, women cycle more than men (Harms, Bertolini, & Brömmelstroet, 2013). Unsurprisingly therefore, BSPs in countries with low cycling usage have lower levels of female participation. For instance, less than 20% of trips by registered users of the London BSP are by women (Goodman & Cheshire, 2014), though this proportion rises slightly when looking at casual users. Interestingly, female participation rises substantially for trips that start or finish in a park, possibly suggesting a desire among females to avoid motorised traffic routes in London and a recreational rather than commuting trip purpose. Previous research has found that women have a stronger preference for traffic free riding (Johnson, Charlton, & Oxley, 2010). A study of Australia's bikeshare members has found that women account for 23% and 40% of annual members in Melbourne and Brisbane, respectively, but it is not clear what accounts for the discrepancy between the two (Fishman et al., 2014). Nevertheless, the proportion of female *CityCycle* members is greater than for private bike riding in Australia (Pucher, Greaves, & Garrard, 2010). Dublin's bikeshare gender split is 22% female (Murphy & Usher, 2015). In one of the few studies of short-term bikeshare users, Buck et al. (2013) found that in intercept surveys of *Capital Bikeshare* users, the gender split was even. The authors expressed doubts as to whether the survey method was valid for calculating a gender difference. In an annual member survey of the same programme 55% of respondents were male, which is broadly in line with the intercept survey results (Buck et al., 2013).

In summary, bikeshare uses are on average disproportionately of higher education and income, more likely to be male and white. The gender disparity does appear to be smaller, however, than for private bike riding.

4. Barriers to Bikeshare

There is a paucity of research examining barriers to bikeshare, in large part because of the difficulty associated with data collection. As identified previously, long-term bikeshare subscribers typically provide an email address as part of the membership sign-up process. No such access is available when gauging the views of those with no known association with bikeshare, and this is compounded by the fact that levels of interest in participating in bikeshare research is lower than for those who have used bikeshare (Fishman, 2014). Nevertheless, a critical need to examine barriers to bikeshare exists, both to improve system attractiveness in those with disappointing usage as well as for informing the design of future BSPs. The following section documents the key finding from the limited research gauging the views without a known connection with bikeshare.

4.1. *Convenience and Safety Concerns*

Motivated in large part by the lower usage level of Australian BSPs, a Brisbane-based panel without a known connection to bikeshare were surveyed regarding their perceived barriers to bikeshare ($n = 60$). The mean scores to the question 'If you were considering joining *CityCycle*, to what extent would these factors discourage you?' are presented in Figure 5. Interestingly, the major barrier to bikeshare, at least for this rather small sample of Brisbane-based non-bikeshare users, was the fact that driving was seen as too convenient. As a related issue, the barrier that received the second strongest response was 'docking stations were considered to be too far from respondents' homes'. This corresponds with a consistent finding from other studies that have found bikeshare members are more likely to live in close proximity to a docking station, in Montreal (Bachand-Marleau et al., 2012), London (Goodman & Cheshire, 2014), Melbourne and Brisbane (Fishman et al., 2014, 2015).

Concerns riding in traffic were also highlighted as a major barrier to bikeshare, and this corroborates qualitative research with Brisbane citizens regarding bikeshare (Fishman et al., 2012a). In recently published research, Fishman et al. (2015) showed those who have not used bikeshare are considerably more sensitive to a lack of bike infrastructure than those who are bikeshare members. For instance, when presented with a picture of a rider in mixed traffic with no

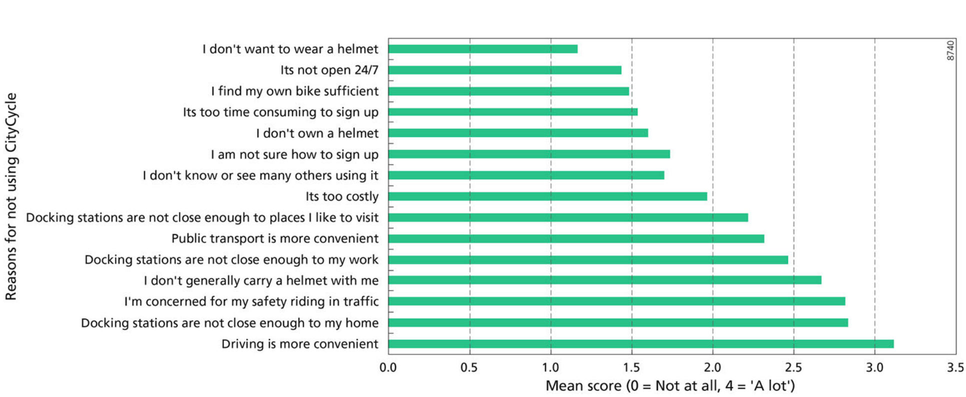

Figure 5. Reasons for not using *CityCycle.*
Source: Fishman (2014).

bicycle infrastructure, 60% of non-BSP members said they felt 'Very unsafe', compared to about 40% for bikeshare members (Fishman et al., 2015). Consistent with this finding, Faghih-Imani et al. (2014) found docking stations integrated with the surrounding bicycle infrastructure network were busier.

4.2. *Mandatory Helmet Legislation*

Helmets have emerged as a contentious issue for bikeshare (Basch, Ethan, Rajan, Samayoa-Kozlowsky, & Basch, 2013). In jurisdictions in which helmet use is mandated by law, such as Melbourne and Brisbane, helmets have prominently featured in bikeshare commentary (Fishman, 2012; Queensland Parliamentary Committee, 2013), and have been implicated in the significantly lower usage levels than other cities (Fishman et al., 2013; O'Brien, Cheshire, & Batty, 2014; Queensland Parliamentary Committee, 2013; Rissel, 2011; Traffix Group, 2012). Indeed Tel Aviv and Mexico City repealed their mandatory helmet law, as a pre-emptive move to boost usage levels (Flegenheimer, 2013). It is interesting to note, however, that in the results illustrated in Figure 5, drawn from a sample with very low levels of cycling participation (of any kind), helmets did not feature as a major barrier to bikeshare. A distillation of the limited literature on this issue appears to suggest that for those who do not ride a bike, there are other, more important barriers to riding than mandatory helmet legislation (Fishman et al., 2015). For those that ride regularly, the requirement to carry a helmet has been shown to have a negative effect on bikeshare (Alta Bike Share, 2011; Alta Planning + Design, 2012; Fishman, 2014; Traffix Group, 2012). This is supported by what might be considered a naturalistic experiment (though the BSP operators did not call it as such), in which freely available helmets were placed on *CityCycle* bikes, and a significant increase in casual usage was recorded (Fishman et al., 2013), although this period coincided with the introduction of a more favourable pricing structure, it suggests increasing immediate access to helmets at the point of departure may help reduce the barrier presented by mandatory helmet legislation.

In a customer satisfaction survey of *CityCycle* subscribers, one in three subscribers reported not wishing to re-subscribe (Roy Morgan Research, 2013), compared to 11% for London bikeshare members (Transport for London, 2014). When asked why they will not be renewing their subscription, 11% cited mandatory helmet laws as the main reason and a further 9% called for the removal of the helmet laws (Roy Morgan Research, 2013). Members of *Melbourne Bike Share* and *CityCycle* both reported using bikeshare less due to mandatory helmet legislation (Fishman & Schepers, 2014).

The lower than expected usage of *CityCycle* has prompted a Parliamentary Committee to recommend

> a 24 month trial which exempts cyclists aged 16 years and over from the mandatory helmet road use when riding in parks, on footpaths, and shared/cycle paths and on roads with a speed limit of 60km/h or less. (Queensland Parliamentary Committee, 2013, p. xvii)

Seattle launched a BSP known as *Pronto* in 2014 and users are required to comply with a pre-existing mandatory helmet law. According to the operators' website, free helmets are available at docking stations. The feasibility study for Seattle's

BSP estimated a 30% reduction in usage due to the mandatory helmet laws (Alta Planning + Design, 2012), although it was not clear how this figure was determined. Issues related to the voluntary use of helmets are discussed in Section 3.2.3.

4.3. *Sign-Up Process*

The speed and ease with which people are able to sign up to a BSP can have an impact on likelihood of using the programme. The vast majority of third-generation BSPs allow prospective users to sign up on the spot, with a credit card. Where this is not the case, users and would-be users have reported the lack of immediate sign-up is a barrier to usage (Fishman et al., 2012a).

This section documents the experience of *CityCycle*, which is among the few third-generation BSPs in English-speaking countries not to offer automated sign-up at docking stations.

The Brisbane City Council commissioned a survey of registered *CityCycle* users (Roy Morgan Research, 2013), emailed to 13 495 long- and short-term subscribers with a response rate of 11.5%. The results showed that one in three *CityCycle* users report not wishing to re-subscribe, with the complex subscription process noted as one of the key reasons short-term subscribers are not repeat *CityCycle* users. Moreover, the complex subscription process was highlighted by 54% of short-term local subscribers as the main area requiring improvement, many of whom noted they would not return as *CityCycle* users (Roy Morgan Research, 2013). The *CityCycle* experience offers an important lesson for bikeshare planners. Users and would-be users value bikeshare's spontaneity (Fishman et al., 2012a) and policies should seek to minimise hurdles associated with becoming bikeshare users.

In summary, the major barriers to bikeshare relate to a lack of convenience and competitive advantage with other modes, safety concerns and anything that impedes spontaneity. There is a critical paucity of research with large samples of non-BSP members and this needs to be addressed in order to better understand how bikeshare can be tailored to be more attractive to those who do not currently view it as a viable option. For a more detailed account of barriers to bikeshare, with an emphasis on the Australian context, readers are encouraged to see Fishman et al. (2014a).

5. Bikeshare: Evaluating the Impacts

There are a number of purported benefits of bikeshare, including travel time saving, connection with public transport, health, air and noise pollution benefits (Shaheen et al., 2013). Added to these is the possibility that bikeshare may serve to *normalise* the image of cycling (Goodman et al., 2014). Implicit in many of the benefits associated with bikeshare is an assumption that bikeshare is used to replace trips previously made by car, yet the data suggest this is seldom the case (Fishman et al., 2014; Midgley, 2011). This section examines the few studies that have evaluated the impacts of bikeshare, covering the impacts on car use, health and safety.

5.1. *Car Use Reduction/Mode Substitution*

A consistent theme to emerge from the literature on the mode bikeshare replaces (mode substitution) is that most of the trips are replacing trips formerly made by

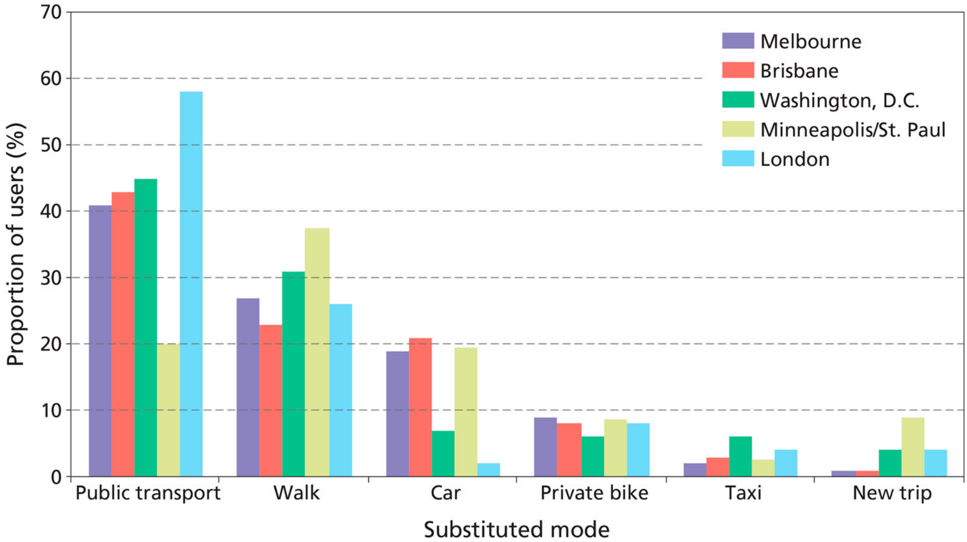

Figure 6. Mode substitution in selected cities.
Source: Melbourne and Brisbane (Fishman et al., 2014a), Washington, D.C. (LDA Consulting, 2012), Minnesota (Nice Ride Minnesota, 2010) and London (Transport for London, 2011)

public transport and walking (Fishman et al., 2015). A study of a BSP in Shanghai showed that the majority of users are replacing walking and public transport (Zhu, Pang, Wang, & Timmermans, 2013). The mode substitution rate for a selection of BSPs for which data is available is provided in Figure 6:

In a multi-city analysis of bikeshare's impact on car use, Fishman et al. (2014a) calculated bikeshare's overall impact on changes to vehicle kilometres travelled. This calculation also included the distance covered by trucks used in re-distribution and maintenance. The results show that in all but one of the cities included in the analysis (the same as those appearing in Figure 6), bikeshare reduces car use. London was the only city in which this was not the case, due to the low car mode substitution rate (2%) and the large distance covered by re-distribution vehicles.

As reduction in car use is a key motivation for the establishment of bikeshare, operators, government and researchers need to focus greater effort to quantitatively measure the degree to which BSPs impact on car use, and consider ways to facilitate this mode shift.

5.2. *Health*

Several studies have attempted to quantify the health impacts of bikeshare, with some focused on one outcome variable, such as changes to physical activity levels, while others attempt to capture a larger range of outcomes. The most comprehensive examination of the health impacts of bikeshare was published by Woodcock et al. (2014) on the London BSP. The researchers focused on three issues; physical activity, crashes and exposure to air pollution. This study used trip data to model the health impacts of the programme via comparison to a scenario in which the programme did not exist. Physical activity was found to increase considerably at the population level. The benefits were shown to differ by gender and age, with men's major benefit coming from reductions in ischaemic heart disease, whereas women were more likely to benefit in terms of reductions in depression. In relation to crashes, the results of the study suggest that on balance, the programme delivers more benefit than harm, although the effects are not uniform for all age groups or gender. Interestingly, the researchers found that more benefit would be gained if users were older, as older people have fewer healthy life years to lose. Conversely, when a young person crashes, they have many more healthy life years at risk. It is important to note, however, that an older person is less likely to fully recover from the same crash that involves a younger person, that is, older people are more vulnerable (Li, Braver, & Chen, 2003). When the researchers applied the general crash risk for all cycling in central London, they found a negative health impact for women, due to the greater fatality rate among female cyclists in London. In terms of air pollution, the study found that while cycling routes typically have slightly lower levels of air pollution (PM2.5), the higher ventilation rate means that on balance, there is little impact of the BSP on air pollution exposure (Woodcock et al., 2014). Overall, the researchers conclude that the greatest health benefit would come from seeing an increase in middle-aged and older people using the scheme.

In another study, Fuller, Gauvin, Morency, Kestens, and Drouin (2013) conducted a cross-sectional telephone survey with some 2500 individuals before and after the implementation of the *BIXI* BSP in Montreal, to determine the potential mode shift and health benefit of the programme. Although the impacts were modest, the authors were able to conclude that *BIXI* was associated with a shift towards active transport.

In the first multi-city analysis of the physical activity impacts of bikeshare, Fishman, Washington, and Haworth (2014b) estimated changes in physical activity due to bikeshare in Melbourne, Brisbane, Washington, D.C., London and Minneapolis/St. Paul. The results suggest an average of 60% of bikeshare trips replace sedentary modes, but when bikeshare replaces walking, a net reduction in physical activity results. Overall, however, bikeshare was found to have a positive impact of physical activity, leading to an additional 74 million minutes of physical activity in London, through to 1.4 million minutes of physical activity in Minneapolis/St. Paul, for 2012 (Fishman et al., 2014b).

5.3. *Road Traffic Injury and Bikeshare*

Perceptions of safety (a lack of) have been established as a major issue for bicycle use generally, in Australia (Fishman, Washington, & Haworth, 2012b), the UK (Horton, Rosen, & Cox, 2007) and the USA (Gardner, 2002). There is growing interest in the safety issues related to bikeshare, including a somewhat volatile debate that straddles the academic and mainstream media, sparked in part by an article published in the American Journal of Public Health (Graves et al., 2014). Graves et al. assessed hospital injury data from five US cities with BSPs and five without, during a 24-month period before BSP implementation and also for a 12-month period post implementation. The non-bikeshare cities essentially acted as a control. What the researchers found but failed to include in their discussion of the results was that there was a dramatic reduction in the total number of hospital-recorded injuries in the bikeshare cities, post implementation. Figure 7 uses data collected by Graves et al. (2014) to illustrate the reduction in recorded injuries in bikeshare cities compared to a slight increase in control cities.

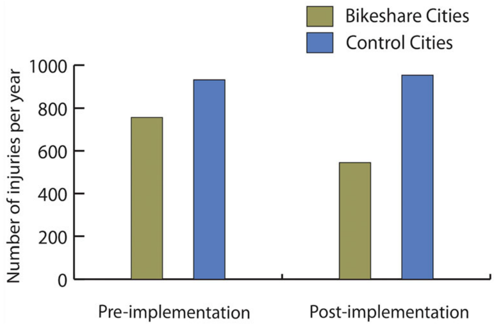

Figure 7. Injuries (all types), bikeshare cities and non-bikeshare cities (control).
Source: Graves et al. (2014)

Graves et al. (2014) conclusions, which have been criticised by other scholars (e.g. Teschke & Winters, 2014; Woodcock & Goodman, 2014), were for bikeshare operators to provide helmets, despite a clear reduction in the number of head injuries for bikeshare cities. The data reported by Graves et al. (2014) are especially significant when considering the overall amount of cycling increases after the introduction of a BSP. This is consistent with the so-called *safety in numbers* phenomenon (Elvik, 2009), in which a rise in the amount of cycling does not lead to a proportional rise in the number of injuries.

In the first multi-city assessment of bikeshare safety that includes exposure factors, Fishman and Schepers (2014) assessed both the distanced travelled and the number of reported injuries on BSPs for 2013 in various US, European and Australian cities. The results showed that on average, there were 1.9 and 0.3 *slight* and *serious* injuries per million kilometres travelled. Of the eight cities included, only one (London) recorded a fatality during 2013, which is too low to reliably calculate a fatality rate for bikeshare systems. When compared to the level of risk for general cycling, bikeshare appears to be considerably safer. The authors suggest that whilst there is no overwhelmingly obvious explanation for this finding, there are several possible contributing factors. First, bikeshare speeds are lower than general cycling. Second, the bikes are more upright than most bicycles (certainly in the USA, the UK and Australia) and this may allow the rider to see and be seen more easily. Finally, Brisbane research showed that bikeshare members felt they received more considerate treatment from motorists than when on their private bicycles (Fishman & Schepers, 2014). The notion that drivers behave differently depending on the appearance of the cyclist has been established previously (Walker, Garrard, & Jowitt, 2014). In a study that contrasts with the aforementioned findings, Fuller et al. (2013) were unable to find a statistically significant difference in collisions or near misses after two years of the *BIXI* programme in Montreal, but expressed caution when interpreting findings, due to a lack of power associated with their sample size.

In summary, despite early concerns regarding the safety of bikeshare users, the levels of serious injury and fatality have been lower than many predicted (Fishman & Schepers, 2014; Woodcock et al., 2014) and some evidence has now emerged to suggest that bikeshare may even be safer than riding private bikes, although the precise mechanisms leading to such an effect require further research.

6. Rebalancing

Rebalancing refers to bikeshare operators moving bicycles across the network, to maintain a reasonable distribution across docking stations (Fishman, 2014). The need for rebalancing is caused when 'tidal flows' of bikeshare trips move *from* or *to* certain areas of a city, such as from residential to commercial zones in morning peak hour. This leads to some stations being completely full while others are empty, and this can lead to a lack of reliability for the user and reduced satisfaction (e.g. Transport for London, 2014), as well as significant costs imposed on operators to manually redistribute the fleet (Fishman et al., 2014a). These twin issues have spurred a diverse range of investigations into effective measures to improve fleet redistribution. Researchers have documented variation between BSPs in different cities regarding the proportion of docking spots that are full or empty (O'Brien et al., 2014) and this may provide a basis upon which cities can begin to reduce the number of docking stations suffering from distribution issues. Rebalancing is a burgeoning sub-topic within bikeshare research. Some researchers have examined the factors associated with higher and lower levels of docking station activity (e.g. Faghih-Imani et al., 2014), finding that weather and the presence of restaurants have a predictable impact of station activity. Other researchers have also identified a relationship between weather and station activity (Rudloff & Lackner, 2013); however, inclement weather is much more likely to impact on casual users than members with a commuting function. Other work has examined the impact of topography on station activity (e.g. Frade & Ribeiro, 2014; Jurdak, 2013). Parkes et al. (2013) suggest altering the price to achieve rebalancing objectives may increasingly be employed as an option to resolve fleet distribution issues.

Some have investigated the effectiveness of providing users with incentives to redistribute bikes, using complex mathematical modelling (e.g. Fricker & Gast, 2014), although in the case of Fricker and Gast (2014) a lack of real-world data collection and the omission of factors known to influence docking station activity (e.g. density) reduces the reliability of the findings. Pfrommer et al. (2013) used historical data on the London BSP to model the effectiveness of employing trucks for redistribution as well as the impact of introducing price incentives to the user to mitigate fleet imbalance. The results suggest that while price incentives may be sufficient on weekends, usage patterns on weekdays are such that a combination of operator and user redistribution is required to maintain an adequate level of service.

This brief introduction to research examining bikeshare redistribution has identified that this is a burgeoning area of research focused on tackling the twin problems of user inconvenience and large operator costs, both of which are incurred when a system is unbalanced. The challenge will be to integrate user preference and behaviour data with appropriate mathematical modelling techniques to test the effectiveness of solutions, ideally with the cooperation of a bikeshare operator. New insights from the field of behaviour economics (Thaler & Sunstein, 2008) may enhance incentive opportunities for users to redistribute bicycles against typical tidal flows.

7. Future Directions

Bikeshare has rapidly emerged as a transport option in an increasing number of cities and as this trend continues, in parallel with technological advancement, a number of future directions appear likely. This section briefly highlights some possible directions for bikeshare in the future as well as emerging research priorities.

7.1. *GPS and Dockless Systems*

As GPS becomes increasingly affordable, it appears likely that in the near future, the benefits will outweigh the costs for BSP operators to install them across their bikeshare fleet. Indeed Copenhagen's new BSP, established in 2014, already has a GPS-embedded fleet as well as on-board tablet computer and Wi-Fi hotspot functionality. Some researchers (e.g. Parkes et al., 2013) have identified that GPS may reduce the need for physical docks and at least one US-based operator (SocialBicycles) operates systems in which on-board solar-powered GPS replaces docking stations. Apart from the obvious security benefits, GPS may assist bikeshare operators by providing a 'geo-fence', detecting when a bicycle has moved outside a given area (Parkes et al., 2013). Operators may also use GPS to assist with the challenging task of re-distributing bicycles across their fleet via the use of real-time tracking. Users may benefit by enhanced real-time information on bicycle availability. The automated data collection offered through GPS provides new opportunities for data analysis, which may not only be useful for bikeshare operators to understand how their system is being used, but also from a wider transport planning perspective. Openly available GeoJSON data files may assist governments plan and evaluate bicycle route usage and effectiveness. These geographic data sets will help build on the impressive work that has begun using start and end docking station locations provided by non-GPS[1] BSPs (see e.g. Beecham & Wood, 2014; Zaltz Austwick et al., 2013).

7.2. *E-bikes and Bikeshare*

The growth of bikeshare noted earlier has coincided with a similarly rapid growth in e-bike performance, affordability and usage. In recent years a number of cities have launched BSPs that offer electric assistance, known as pedelecs[2] (e-bikeshare). These cities include the European capitals of Copenhagen ($n = 250$, with 1860 planned by mid-2015) (Mulligan, 2014, GoBike Numbers: Personal communication) and Madrid with 1560 bicycles (BiciMAD, 2014), as well as a handful of small Italian cities (Meddin, E-bikes and bikeshare: Personal communication, October 13, 2014). There are currently over 14 e-BSPs in Italy as well as one in Stuttgart and at least two in Japan (Meddin, E-bikes and bikeshare: Personal communication, October 13, 2014). Barcelona and Milan both plan to introduce e-bikeshare as part of their existing systems in 2015 (Meddin, 2014, E-bikes and bikeshare: Personal communication, October 8). A university-based e-BSP has been trialled in the USA (Langford, Cherry, Yoon, Worley, & Smith, 2013).

E-bikeshare offers the potential to increase the attractiveness of bikeshare to those who may not have previously seen it as an option. Longer trips, challenging topography, excessive heat and other factors associated with physical exertion can act as barriers to transport cycling generally (Heinen, van Wee, & Maat, 2010). Furthermore, many bikeshare cities have experienced re-balancing issues associated with the city's topography. It is typical for users to ride downhill and show a reluctance to return bicycles to stations located at a higher elevation (Jurdak, 2013). E-bikes may assist in reducing this flow imbalance. Some cities (e.g. Brisbane) have avoided placing docking stations in hilly suburbs, on the assumption that it will cause redistribution issues. E-bikeshare may therefore assist both users as well as bikeshare operators and may be especially applicable in hilly, hot or dispersed cities.

7.3. *Future Research Priorities*

A number of critical bikeshare research priorities are evident from this review. The need to develop more efficient methods of fleet rebalancing presents researchers with a complex analytical challenge. The data captured by modern bikeshare systems have already started to offer researchers a platform to embark on this challenge. This work is still in its embryonic stages and needs to better utilise the principles of behavioural economics, to incentivise users to rebalance, lowering the need for fleet rebalancing by operators.

There is a paucity of research with large numbers of people who are *not* bikeshare users. Such studies are of critical importance to bikeshare user growth, particularly in underused systems. The reaction of drivers to bikeshare users is another little researched area, but early investigations indicate that drivers may react differently to bikeshare riders than general cyclists, but more work applying quantitative methods (e.g. ultrasonic measurement of overtaking distance) is required to better understand whether awareness and behaviour of drivers do differ in the presence of a bikeshare user and, if so, why. Such research may have important implications for road safety. Researchers also need to develop standard, justifiable tools to measure the impacts of bikeshare, in terms of climate change, congestion, air and noise quality, as well as health and time savings. These are the purported benefits of bikeshare, yet little has been established to create a comparable methodology for quantifying these benefits. As noted in this review, no country has the bikeshare scale of China, yet research activity does not reflect this. A much greater focus on Chinese bikeshare needs to occur, as the sheer scale of their systems may provide important insights not just for China but for bikeshare generally. Finally, an international bikeshare research and data centre, supported by governments, universities and the bikeshare industry, would help coordinate research leading to improved research and transport outcomes.

8. Conclusions

Few predicted bikeshare's rapid rise. The research community has been quick to examine the spectrum of issues associated with bikeshare, including user preferences and demographics, usage rates and geospatial visualisations, safety, redistribution options and technological innovation.

The key themes emerging from this review of recent literature are threefold. First, bikeshare users have demographic characteristics that differ from the general population. Users are more likely to be White (in the USA and London at least), male, have higher average incomes and education and more likely to live and work in the inner city, close to or within the BSP catchment area. Second, the literature consistently finds that *convenience* is the major factor motivating bikeshare users to sign up and corroborates with the concept of *perceived usefulness* found by other researchers (e.g. Wolf & Seebauer, 2014 in their examination of e-bike ownership). This finding can be used by those evaluating existing or planning new BSPs; ensuring the *value proposition* provided by bikeshare is competitive with other transport options can enhance ridership. Third, bikeshare's performance in replacing motor vehicle trips has been less than most expected and future efforts to transfer trips previously done by car to bikeshare will help underpin the potential benefits of bikeshare.

Given the speed with which bikeshare literature has developed over the last two years, not every paper and topic has been covered in this review. Several important topics have been omitted and these include bikeshare and public transport integration, different models of provision (e.g. advertising/sponsorship vs. taxpayer funded) as well as big data analysis and geospatial visualisations (covered in a separate article of this *Special Issue*).

Disclosure statement

No potential conflict of interest was reported by the author.

Notes

1. These typically use Radio Frequency ID tags to log bikes leaving and returning to docking stations.
2. Pedelecs offer electrical assistance only when the rider is pedaling, with a cut-off after a certain speed is reached, typically no more than 25 km/h.

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