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Bikeshare's impact on active travel: evidence from the United States, Great Britain, and Australia

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Abstract

Over 800 cities globally now offer bikeshare programs. One of their purported benefits is increased physical activity. Implicit in this claim is that bikeshare replaces sedentary modes of transport, particularly car use. This paper estimates the median changes in physical activity levels as a result of bikeshare in the cities of Melbourne, Brisbane, Washington, D.C., London, and Minneapolis/St. Paul.

This study is the first known multi-city evaluation of the active travel impacts of bikeshare programs. To perform the analysis, data on mode substitution (i.e. the modes that bikeshare replaces) were used to determine the extent of shift from sedentary to active transport modes (e.g. when a car trip is replaced by bikeshare). Potentially offsetting these gains, reductions in physical activity when walking trips are replaced by bikeshare was also estimated. Finally a Markov Chain Monte Carlo analysis was conducted to estimate confidence bounds on estimated impacts on active travel given uncertainties in data sources.

The results indicate that on average 60% of bikeshare trips replace sedentary modes of transport (from 42% in Minneapolis/St. Paul to 67% in Brisbane). When bikeshare replaces a walking trip, there is a reduction in active travel time because walking a given distance takes longer than cycling. Considering the active travel balance sheet for the cities included in this analysis, bikeshare activity in 2012 has an overall positive impact on active travel time. This impact ranges from an additional 1.4 million minutes of active travel for the Minneapolis/St. Paul bikeshare program, to just over 74 million minutes of active travel for the London program.

The analytical approach adopted to estimate bikeshare's impact on active travel may act as the basis for future bikeshare evaluations or feasibility studies.

1. Introduction

Modern, urban lifestyles have engineered physical activity (PA) out of everyday life and this has resulted in an emerging, widespread threat to population health caused by sedentary lifestyles (Garrard, 2009; Hobbs, 2008). It is estimated that physical inactivity causes 21-25% of the burden of disease from breast and colon cancer and even greater proportions for diabetes (27%) and ischaemic heart disease (30%) (World Health Organisation, 2009).

Physical activity is increasingly regarded as the *'best buy'* in preventative health measures (Bauman et al., 2009). Walking and cycling represent one of most effective methods of building PA into daily life (Scheepers et al., 2013). Active transport avoids the pollution and congestion caused by motorised forms of transport (Bauman et al., 2008). The World Health Organisation recommends healthy adults (18 – 64 years old) should engage in a minimum of 150 minutes of moderate intensity aerobic activity throughout the week (World Health Organisation, 2010) and bike use has been found to achieve the necessary intensity to qualify for moderate-intensity activity (Ainsworth et al., 2011; Gojanovic, Welker, Iglesias, Daucourt, & Gremion, 2011; Simons, Van Es, & Hendriksen, 2009; Sperlich, Zinner, Hebert-Losier, Born, & Holmberg, 2012). Bikeshare use represents a potentially important opportunity for people in urban areas to increase PA levels (Woodcock, Tainio, Cheshire, O'Brien, & Goodman, 2014).

1.1 Global growth of bikeshare

Bikeshare programs have become an increasingly popular initiative in an expanding number of cities in Europe, China and North America. There are now over 800 bikeshare programs in operation around the world (Meddin, 2015), from just a handful in the 1990s. The first bikeshare program was launched in Amsterdam in the 1960s, but failed due to a complete lack of security mechanisms (DeMaio, 2009). The most recent decade has seen a sharp increase in both their prevalence and popularity worldwide (Institute for Transportation & Development Policy, 2013; Larsen, 2013), largely due to increasingly available and affordable payment and security technologies (Fishman, Washington, & Haworth, 2013a), coupled with growing interest in urban cycling (Pucher & Buehler, 2012)

In 2007, Paris launched Europe's largest scheme, with over 20,000 bicycles. Hangzhou in China currently has among the world's largest bikeshare programs, with 78,000 bikes. Wuhan has closed its bikeshare program at the time of writing, but at its height had up to 90,000 bicycles (Meddin & DeMaio, 2014). New York City launched North America's largest bikeshare program, with 6,000 bikes in May, 2013, and is set to grow to 10,000 bikes in the future. There are currently an estimated 946,000 bicycles in the global bikeshare fleet (Meddin, 2015).

1.2 Factors associated with bikeshare use and benefits

Convenience has emerged as the most important factor associated with bikeshare use. Bachand-Marleau et al. (2012) found convenience and the avoidance of private bike theft and maintenance to be key facilitators to the use of the *BIXI* program in Montreal. These findings are generally supportive of an earlier study by Fuller et al. (2011) of the same program. Convenience was the main motivating factor for bikeshare users in North America (LDA Consulting, 2012; Nice Ride Minnesota, 2010; Shaheen, Martin, Cohen, & Finson, 2012), China (Shaheen, Zhang, Martin, & Guzman, 2011), London (Transport for London, 2011a) and Australia (Alta Bike Share, 2011; Fishman, Washington, & Haworth, 2012; Fishman et al., 2013a; Traffix Group, 2012).

Proximity to a bikeshare docking station (where bicycles are picked up and dropped off) has been established as a reliable predictor of bikeshare usage. Bachand-Marleau et al. (2012) found that living within 500m of a docking station resulted in a three-fold increase in the odds of *BIXI* use. In London, Ogilvie & Goodman (2012) found bikeshare members who lived close to docking stations used the system more than members living further away. Fun has also been found by some researchers to motivate bikeshare use, particularly casual users (i.e. those who are not registered members) (LDA Consulting, 2013; Transport for London, 2011b).

Shaheen et al. (2010) summarise the benefits of bikeshare as flexible mobility, emission reductions, reduced congestion and fuel use, individual financial savings and support for multimodal transport connections. These programs also offer governments the opportunity to showcase and market eco-friendly mobility aspects of their city (Bachand-Marleau et al., 2012).

1.3 Physical activity benefits of bikeshare

Bikeshare's impact on health is an area of increasing interest to researchers (Fuller, Gauvin, Kestens, Morency, & Drouin, 2013b; Rojas-Rueda, de Nazelle, Tainio, & Nieuwenhuijsen, 2011; Woodcock et al., 2014). Implicit in many of the benefits attributed to bikeshare is an assumption that bikeshare journeys frequently replace trips previously made by car. International evidence suggests this is seldom the case (Fishman, 2012; Fishman et al., 2013a; Midgley, 2011), partly due to the fact that systems are predominately focused in the inner city, where car use may not be the dominant mode. Nevertheless, a number of studies have been able to demonstrate bikeshare's impact on health. Amongst the most comprehensive analysis of the health impacts of bikeshare, Woodcock et al. (2014) evaluated the London bikeshare program, in terms of air pollution, crash risk and PA. This study used trip data to model the health impacts of the program via comparison to a scenario in which the program did not exist and found that PA was considerably increased at the population level. The benefits for both sexes were larger for older ages groups. In another study, Fuller et al. (2013b) conducted a cross sectional telephone survey with some 2,500 individuals before and after the implementation of the *BIXI* bikeshare program in Montreal, to determine the potential mode shift and health benefit of the program. Although the impacts were modest, the authors were able to conclude that *BIXI* was associated with a shift towards active transport.

This paper seeks to examine net changes to active travel as a consequence of bikeshare. It builds on previous research by providing the first multi-city analysis of the impact of bikeshare on active travel. It does this by examining estimated changes in duration from sedentary to active modes. Importantly, this paper also accounts for changes to active travel associated with shifts from walking to bikeshare. The importance of this element is that walking offers greater PA benefits per kilometre travelled than does bicycling (New Zealand Transport Agency, 2009), as cycling is quicker than walking and offers the ability to "coast" on suitable gradients. These two components are then combined to provide an illustration of bikeshare's overall impact on active travel. Therefore, the specific research question this paper seeks to address is *'what impact do bikeshare programs have on active travel?'* The analytical approach of this paper may be adapted for future research evaluating bikeshare impacts.

2. Methodology

The bikeshare programs of Melbourne, Brisbane, Washington, D.C., London, and Minneapolis/St. Paul are examined in this paper. These programs have all been established since 2010 and are considered I.T. based systems, relying on electronic payment and tracking technology, enabling automated rental and returns. The authors have analysed the data log for each of the above bikeshare programs. This log contains information on each trip taken throughout 2012. Each system runs 365 days per year, with the exception of Minneapolis/St. Paul, which was open from April 8th to November 7th, 2012. Each trip has a start and end date and time, as well as the origin and destination docking station. Trips of less than two minutes or greater than three hours have been omitted from our analysis. This decision was made on an assumption that such trips are unlikely to represent genuine bicycle riding time but rather a result of operator or technical error (e.g. a bicycle not removed or docked correctly). Trip duration was determined by subtracting trip end time from trip start time.

The aforementioned methodology is transferable to other cities, providing the necessary data can be obtained. It is difficult to generalize the results to other cities, as this is highly dependent on mode substitution rates, which vary from city to city (Fishman, Washington, & Haworth, 2014).

2.1 Mode substitution

To evaluate the impact of bikeshare on active travel, it is necessary to have an understanding of the degree to which bikeshare replaces other modes of transport (mode substitution). The members of the bikeshare programs included in this study were asked to participate in separate online surveys. These surveys were wide-ranging but contained a common question - "*Thinking about your last journey on bikeshare, which mode of transport would you have taken had it not existed?"*[1] These surveys were conducted as independent activities and carried out or commissioned by the operators of each program (with the exception of the Australian programs which were undertaken by the authors). The operators of the bikeshare program in Minneapolis/St. Paul, *Nice Ride Minnesota* conducted a survey sent out to subscribers in 2010 (Nice Ride Minnesota, 2010). *Capital Bikeshare* in Washington, D.C. commissioned a study of members in 2012 carried out by LDA Consulting (2012). In 2011 Transport for London ran a survey for members of *Barclays Cycle Hire* (Transport for London, 2011a). The authors of the current study included a mode substitution question in an online survey sent to members of the Melbourne and Brisbane bikeshare programs. Figure 1 documents the results to this question, across the aforementioned bikeshare programs. A small proportion of bikeshare trips are considered *new* (i.e. would not have occurred had it not been for the presence of bikeshare). It is assumed these trips replace sedentary activities.

2.2 Impact on active travel

Once mode substitution rates have been collected and the data log of bikeshare trips cleaned and analysed, it is possible to estimate the impact of bikeshare on active travel. This task is broadly divided into two components. Firstly, the additional minutes of active transport associated with transfers from sedentary modes to bikeshare is calculated. The second set of calculations involved determining the impact on active travel time resulting from shifts to bikeshare from walking, described in Section 2.2.1.

2.2.1 Assumptions for walking mode substitution

When a bikeshare trip places a journey previously made on foot, a number of considerations need to be made to determine its overall impact on active travel time. Firstly, walking provides PA benefits and therefore anything that reduces minutes spent walking must be included in a calculation of total active travel impact. An assumption has been made that a bikeshare trip substituting for walking would be one-third the duration of the same trip done on foot. The basis of this assumption is that typical walking speed is approximately one third the average bikeshare speed. For example, a 15-minute walk would translate to about a 5-minute bikeshare journey.

Related to the first assumption, a second assumption has been made that when a person substitutes walking for bikeshare, the average bikeshare journey will only be 5-minutes in duration. This assumption is based on the fact that when bikeshare substitutes for walking, the trip by foot is highly likely to have been substantially shorter than a trip that, for example, substitutes for a car or public transport journey. For instance, a typical bikeshare journey is around 16 minutes (Fishman et al.,

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[1] The wording of this question varied slightly; In Melbourne (n = 372) and Brisbane (n = 443) it was presented as shown. In Washington, D.C: *"If Capital Bikeshare had not been available, how would you have made your most recent trip"* (n = 5,287). In Minneapolis/St. Paul: *"Please recall the most recent trip you took using a Nice Ride bicycle"* (n = 685). In London: *"Before the Barclays Cycle Hire Scheme was introduced last July, how would you have typically made this trip?"* (n = 2,177).

2014). If such a bikeshare trip had taken place on foot instead, the journey would have taken approximately 45-50 minutes, which is considerably longer than most urban walking trips (Central Bureau of Statistics, 2014; Merom, van der Ploeg, Corpuz, & Bauman, 2010; Transport for London, 2011b). In London, the average walking trip is about 17 minutes (Transport for London, 2011b). Finally, when an individual transfers from walking to bikeshare, they save time (as cycling is faster than walking). In this analysis, it is assumed the saved time was not used to engage in moderate or intense physical activity.

2.2.2 Estimates on active travel impact

To calculate the overall change in active travel minutes, a series of sequential formulas were derived and are shown below. While estimates of the impact on active travel for each city are provided, it was also thought necessary to estimate 95% confidence bounds around the estimates of bikeshare impact on active travel. It is noteworthy that uncertainty bounds are provided for numerous mean estimates, such as trip durations and mode substitution rates, as uncertainty in estimates is essential to calculate confidence in final estimates. While total number of trips reported is assumed to be accurate by the program providers (stations are monitored by computer), for purposes of uncertainty estimation it is assumed here that total number of trips was measured within ± 2% precision.

To calculate 95% confidence intervals for the impact on active travel in each city, a Markov Chain Monte Carlo (MCMC) simulation was performed using equation 6, with uncertainties in estimates captured in the simulation as specified in equations 1, 2, 3, and 4. This approach is necessary as the uncertainties in measurement are not simply additive, depend on sample sizes, and are well suited for a simulation based approach.

The estimated average total minutes of riding (*MinBike*) in city *i* is a product of the estimated number of trips (assumed to be uniformly distributed within 2% of the estimates provided by system managers) and the mean trip duration—the mean of a sample of Generalised Extreme Value (GEV) distributed trip durations (for the MCMC simulation 1000 random samples were drawn) with sample estimated distribution parameters $\delta, \psi, \text{and } \kappa$, as shown in Equation (1):

$$\begin{aligned} &MinBike_i = \left(NumTrips_i\right)\left(MeanTripDur_i\right) \\ &TripDur_i : \ GEV(\delta_i, \psi_i, \kappa_i) \\ &NumTrips_i : \ Uniform\left(Num\hat{T}rips_i + 2\%, Num\hat{T}rips_i - 2\%\right) \end{aligned} \tag{1}$$

For the shift from car, taxi, and public transport (PT) modes to bikeshare, the estimated total minutes for city *i* and mode *j* (j =1, 2, and 3 for car, taxi, and PT) is the product of total minutes of riding and the mode substitution rate for each city and mode, where each mode substitution rate is approximately normally distributed with mode share proportion $\pi_{i,j}$, and standard deviation and sample size as shown in Equation (2):

$$\begin{aligned} &\text{ShiftToBikeshare}_{i,j} = \left(MinBike_i\right)\left(ModeSubRate_{i,j}\right) \\ &ModeSubRate_{i,j} : \ Normal\left(\pi_{i,j}, \sqrt{\frac{\left(\pi_{i,j}\right)\left(1-\pi_{i,j}\right)}{n_i}}\right) \end{aligned} \tag{2}$$

The estimated total minutes from new trips to bikeshare for city *i* is the total minutes times the new trip rate, where the new trip rate is approximately normally distributed with new trip mode share proportion η_i, as shown in Equation (3):

$$\begin{aligned}&\text{NewBikeshareTrip}=\left(MinBike_i\right)\left(NewTripRate_i\right)\left(NumTrips_i\right)\\&NewTripRate_i \sim Normal\left(\eta_i,\sqrt{\frac{(\eta_i)(1-\eta_i)}{n_i}}\right)\end{aligned} \tag{3}$$

The estimated amount of walking in minutes not undertaken (a reduction in PA) is a product of total trips taken, and the walking mode substitution rate ω_i, which is again approximately normally distributed, as shown in Equation (4) and an assumed travel duration of 15-minutes (see Section 2.2.1):

$$\begin{aligned}&\text{WalkingRepl}_i=-\left(NumTrips_i\right)\left(WalkSubRate_i\right)\left(15\right)\\&WalkSubRate_i \sim Normal\left(\varpi_i,\sqrt{\frac{(\varpi_i)(1-\varpi_i)}{n_i}}\right)\end{aligned} \tag{4}$$

The estimated amount of PA in minutes from people switching from walking to bikeshare is the product of total trips and the walking substitution rate, and 5 minutes—the assumed trip duration (see Section 2.2.1). This equation incorporates the fact that a trip that would have been walked has 3 times the typical duration of the same trip by bikeshare, and also assumes that a bikeshare trip that substitutes for walking would have only been a 5-minute bikeshare Mintrip (a 15-minute walk). Naturally, it also includes the transfer from sedentary modes to bikeshare.

$$\text{WalktoBikeshare}_i=\left(NumTrips_i\right)\left(WalkSubRate_i\right)\left(5\right) \tag{5}$$

To calculate the overall mean impact on PA (ΔPA_i) in minutes for city *i*, Equation (6) was used, incorporating Equations (1) – (5). An MCMC simulation with 50,000 burn-in iterations and 25,000 samples to derive median, 90% and 95% confidence intervals around PA in each of the cities studied in this analysis.

$$\Delta\text{PA}_i=\left(\sum_j \text{ShiftToBikeshare}_j\right)_i+\text{NewBikeshareTrip}_i+\text{WalkRepl}_i+\text{WalktoBikeshare}_i \tag{6}$$

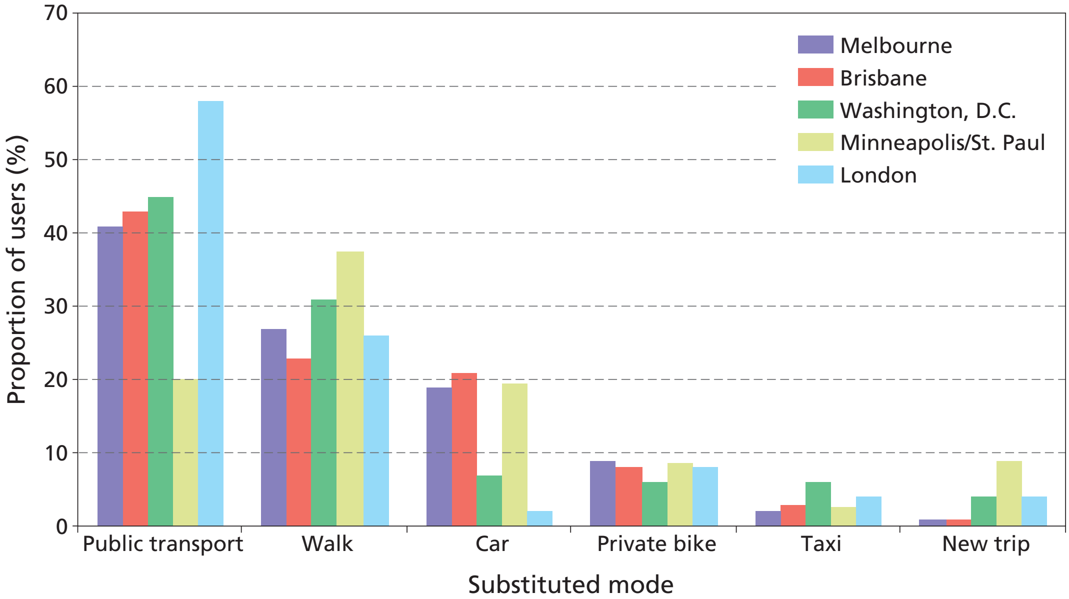
3. Results and discussion

3.1 Mode substitution

A substantial proportion of trips currently taken on bikeshare in the cities included in this study were found to substitute for public transport and walking. This is consistent with a study of the Montreal bikeshare program (Fuller et al., 2013b). London has the lowest level of car substitution, which is broadly in line with the lower proportion of trips undertaken by car, relative to the other cities included in this analysis.

The transfer from sedentary mode (e.g. car, public transport, taxi) to bikeshare ranges from 51% of trips in Minneapolis/St. Paul to 68% in both Brisbane and London. Minneapolis/St. Paul's relatively low rate of transfer from sedentary modes is primarily due to very high rates of mode substitution from walking. London recorded a very high rate of mode substitution from public transport, whereas Brisbane, Melbourne and Minneapolis/St. Paul each recorded relatively high rates of car mode substitution, which is consistent with higher rates of car use in these cities (Australian Bureau of Statistics, 2013; United States Census Bureau, 2013). Figure 1 provides a full illustration of mode substitution rates.

Figure 1 Mode substitution in selected cities.



Source: Melbourne and Brisbane (Fishman, Washington, & Haworth, 2013b), Washington, D.C. (LDA Consulting, 2012) Minneapolis/St. Paul (Nice Ride Minnesota, 2010) London (Transport for London, 2011a).

3.2 Bikeshare fleet size and usage

Table 1 presents the key metrics used to estimate bikeshare's impact on PA. It is clear from Table 1 that there are some large differences in the magnitude of the bikeshare programs included in study, with London having some 8,000 bicycles, whereas Melbourne for instance only has 600. When looked at on a *per bike* basis, there are differences as well, with a bicycle in the Brisbane fleet used once every three days on average, compared to three times per day for London. For each city, the amount of riding time was calculated using the number of trips multiplied by mean trip duration.[2]

Table 1: Bikeshare size and usage (2012)

	Melbourne	Brisbane	Washington, D.C.	Minneapolis/ St. Paul	London*
Bikes^	600	1,800	1,800	1,325	8,000
Trips# (2012)	138,548	209,232	2,008,079	268,151	9,040,580
Trips per day per bike	0.6	0.3	3.0	0.9	3.1
Mean trip duration# (median in brackets)	22.0 (13.5)	16.2 (13.1)	15.8 (10.9)	17.5 (11.4)	17.5 (13.0)
Total ride time (min.)	3,048,056	3,389,558	31,727,648	4,692,643	158,210,150
Annual members	921	1,926	18,000	3500	76,283
Regional population[3]	3,999,980	2,065,998	5,860,342	3,759,978	7,170,000

Source: Trips and duration: Melbourne (Hoernel, Unpublished data), Brisbane (Lundberg, Unpublished data), Minneapolis/St. Paul (Vars, Unpublished data), London (Stanhope, Unpublished data), Washington, D.C. (Capital Bikeshare, 2013), Estimated travel speed (Jensen, Rouquier, Ovtracht, & Robardet, 2010).

^Fleet total, which may not reflect actual number of bicycles in circulation.

#Trips < 2 minutes and > 3 hours excluded from analysis. Non-normal distribution.

*In March 2012, London's bikeshare fleet rose from approximately 6,000 bikes to 8,000 bikes. Serco (bikeshare operator) experienced data loss between 1st January – 3rd January and 5th February – 28th February 2012. Estimates used for missing trip data during these dates based on activity either side of data loss period. Trips less than 4 minutes duration removed by Serco between 29th April – 18th August 2012 (unrecoverable). Regional population: Brisbane and Melbourne (Australian Bureau of Statistics, 2013), London (Greater London Authority, 2012), Minneapolis/St. Paul (Minneapolis/St. Paul Combined Statistical Area) (Wikipedia, 2013) and Washington, Metropolitan Area (Wikipedia, 2012).

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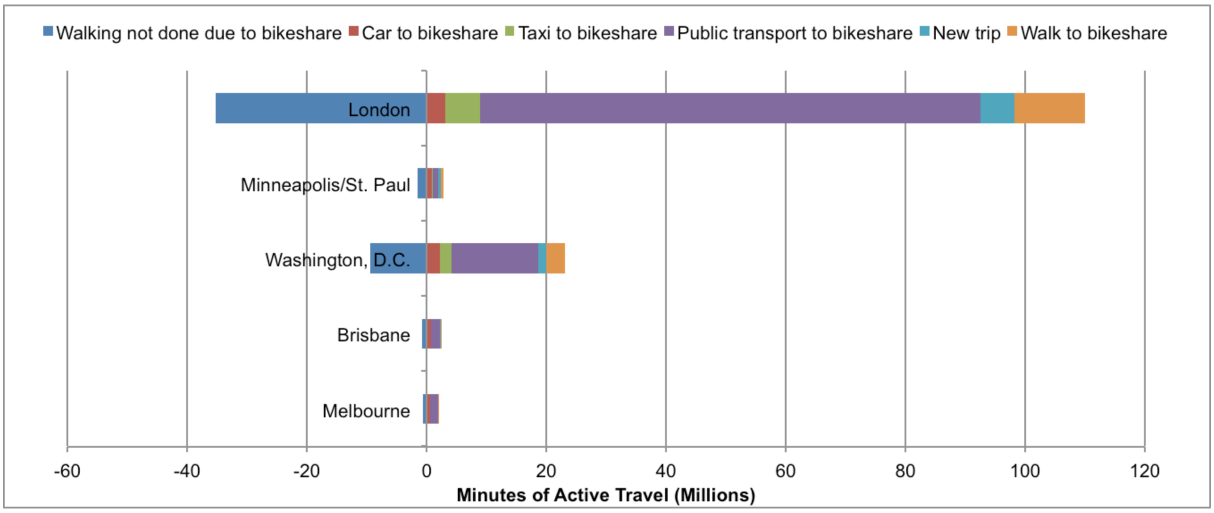
[2] This is the bikeshare trip duration, rather than the duration of the substituted trip, which is unknown.

[3] Method of demarcating regional boundaries differs and those interested are encouraged to examine cited sources.

3.3. Bikeshare's impact on active travel

Bikeshare's impact on active travel is very much dependent on the mode bikeshare replaces. When bikeshare replaces a sedentary mode, there is a net active travel gain, whereas when walking is replaced by bikeshare, there is a net loss in minutes of active travel (see Section 2.2.1 for assumptions). Figure 2 provides an illustration of changes to active travel duration due to bikeshare. All cities included in this study show a positive impact on active travel levels and this broadly supports the findings of previous studies (Fuller et al., 2013a; Woodcock et al., 2014). It is interesting to note that active travel gained when bikeshare substitutes for car use is in many cases a minor contributor to active travel minutes, due to the generally quite small degree to which car use is replaced by bikeshare. Importantly, Figure 2 also shows the negative impact on active travel when a bikeshare trip replaces walking. See Table A1 in the Appendix for data that acts as the basis for Figure 2.

Figure 2 Estimated changes to active travel due to bikeshare.



NB: Due to scale differences caused by the magnitude of London's values, readers are encouraged to refer to Table A1 in Appendix 1 for precise values of all cities.

The net change in active travel due to bikeshare is shown in Table 2. In essence, Table 2 is the sum of the positive impact of bikeshare on active travel, minus the negative effect when bikeshare replaces a trip previously made by foot. The results of the MCMC simulation are shown in Table 2, providing estimates of bikeshare's impact on active travel, accounting for the uncertainty known about the provided estimates.

The correct interpretation of the confidence intervals is that if a system was set up just like Brisbane, 95 out of 100 systems would yield an increase between 1.72 and 2.02 million minutes per year as a result of switches from other modes to bikeshare trips. The uncertainty estimates account for the uncertainty in reported trip durations, mode shares, and reported total number of trips by system operators. The London system had the largest impact on active travel, with between 68.90 and 80.80 million additional minutes of active travel per year with 95% confidence.

Table 2 Estimated millions of minutes of addition active travel due to bikeshare using Markov Chain Monte Carlo (MCMC) simulation

City	2.5% CI	5% CI	Median	95% CI	97.5% CI
Brisbane	1.72	1.73	1.86	2.00	2.02
Melbourne	1.38	1.40	1.55	1.73	1.79
Minneapolis/St. Paul	1.24	1.24	1.40	1.60	1.65
Washington DC	12.11	12.35	13.80	15.55	16.10
London	67.91	68.90	74.37	80.80	82.23

NB: CI is Confidence Interval

4. Limitations

Although every reasonable action was undertaken to ensure the validity of the results, there are several notable limitations. Trip usage data may contain technical errors, although this was mitigated by omitting all journeys recorded as being below two minutes or greater than 180 minutes duration. Such trips are likely to be the result of user or technical error rather than a genuine trip. An assumption was made that bikeshare trip length is the same as a substituted car trip. Data from Lyon suggests bikeshare trips are often shorter than the same trip by car (Jensen et al., 2010), however this may not be true of the cities included in this study.

The sample groups in all cities included in Figure 1 are registered bikeshare members, as distinct from casual users. It is plausible that casual members may differ in their mode substitution patterns and previous research from Washington, D.C. (Virginia Tech, 2012) and Montreal (Morency, Trepanier, & Godefroy, 2011) has identified differences between registered and casual users. The proportion varies by city and season, but based on data from Melbourne, approximately 55% of trips were by annual members in 2012 (Royal Automobile Club of Victoria, 2014).

The underlying PA level of bikeshare users is not known and therefore cannot be incorporated in the analysis. Caution must therefore be exercised when attributing PA benefits to bikeshare use, as the benefits associated with PA are dose dependent (Foulds, Bredin, Charlesworth, Ivey, & Warburton, 2014). If an individual's level of PA already meets guidelines, additional PA through bikeshare may provide little health benefit, whilst continuing to expose the user to injury risk. It is also possible that bikeshare users are forgoing other forms of PA (such as going to the gym), due to their bikeshare usage. It may also be possible that for those users saving time riding instead of walking might use that time to engage in PA. The authors are not aware of any studies evaluating these possibilities and this gap therefore exists as a limitation of the current study. Moreover, the authors were forced to make assumptions regarding variation in duration of bikeshare trip depending on the mode replaced by bikeshare. Further research is required to determine how bike share trip duration may vary based on the mode it is substituting, as it is plausible a trip substituting for walking may be shorter than one replacing a car journey. The new trips bike share generates (see Figure 1) were assumed to replace sedentary activities, however it is of course possible that these bikeshare trips replaced moderate or intense PA, such as visiting a gym.

Markov Chain Monte Carlo simulation was used to account for uncertainty related to these issues. Most public transport journeys also include some walking (Brown & Burke, 2007), however this analysis was unable to confidently estimate this for the purposes of bikeshare use. In any case, walking to a bikeshare docking station may cancel this effect, consistent with previous studies (Woodcock et al., 2014). Furthermore, this paper has not assessed PA impacts of bikeshare at the individual level. Rather, it has aggregated usage and expressed the number of hours of active travel bikeshare has facilitated.

Whilst bikeshare's impact on active travel is the focus of this paper, the authors do not imply that increased PA is the only benefit of bikeshare. Additional potential benefits of bikeshare found by other researchers include greater transport choice (Shaheen et al., 2012), travel time savings (Woodcock et al., 2014) and reductions in transport costs (LDA Consulting, 2013). Bikeshare programs may also ultimately encourage private bike use (Transport for London, 2011b) and assist in normalising the image of cycling (Goodman, Green, & Woodcock, 2013) and this may have an important impact on population health as well.

5. Conclusions

Bikeshare has developed rapidly over the past decade, particularly in North America, Europe and China. An implicit assumption that equates bikeshare use with car use reduction has emerged, despite evidence showing that only a minority of bikeshare journeys are replacing car trips.

This paper has used ridership and mode substitution data from bikeshare programs in Melbourne, Brisbane, Washington, D.C., London, and Minneapolis/St. Paul to assess the impact of these programs on minutes of active travel. The results are broadly in line with previous studies (Fuller et al., 2013b; Woodcock et al., 2014), showing an overall positive relationship between bikeshare and active travel levels. Importantly, this paper has demonstrated via a multi-system analysis, that bikeshare programs consistently increase overall levels of active transport, even when accounting for the loss when bikeshare replaces walking. This impact ranges from an additional 1.4 million minutes of active travel for the Minneapolis/St. Paul bikeshare program, to just over 74 million minutes of active travel for the London program. The present study attempted to account for the different trip durations associated with a walking and bikeshare journey and the subsequent impact this has on overall levels of active travel. The results demonstrate that in order for bikeshare programs to improve their impact on active travel levels, it is necessary to implement measures focused on encouraging mode shifts from car, taxi and even public transport to bikeshare. As most bikeshare programs are relatively new, few have specifically attempted to attract those using sedentary modes, but this paper has demonstrated that such efforts may be well justified in terms of active travel impact.

Future research is required to assess the PA levels of bikeshare users (outside of bikeshare) and any compensatory behaviour involving replacement of other forms of PA such as visiting a gym, with bikeshare. Monetising the impact of the active travel gained through bikeshare will also help to understand the economic costs and benefits of bikeshare.

Finally, this paper has provided the foundational elements for estimating the impacts of bikeshare on travel patterns and outcomes related to fuel use, emissions, congestion and PA, as well as accounting for inherent uncertainty in estimates along the way. Researchers can adapt the analytical approach proposed in this paper to assist in the evaluation of current and future bikeshare programs.

6. Disclaimer

Only the listed authors contributed directly to this study. This document and the views and opinions expressed in it, do not reflect the views and opinions of Brisbane City Council, VicRoads or MBS and this document does not represent Brisbane City Council, VicRoads or MBS policy. Brisbane City Council, VicRoads and MBS give no warranty or representation about the accuracy or fitness for any purpose of the information and expressly disclaim liability for any errors and omissions in its contents.

Appendices

Table A1: Estimated median changes to active travel (PA), in minutes due to bikeshare mode substitution

	Melbourne	Brisbane	Washington, D.C.	Minneapolis/St. Paul	London
Car to bikeshare	579,800	727,500	2,220,935	898,800	3,164,203
Taxi to bikeshare	61,030	103,900	1,938,000	141,000	5,776,000
Public transport to bikeshare	1,251,000	1,490,000	14,530,000	939,700	83,610,000
New trip	30,520	34,640	1,292,000	422,900	5,776,000
Walking not done due to bikeshare	-561,200	-739,200	-9,339,000	-1,488,000	-35,260,000
Walk to bikeshare	187,040	240,617	3,112,522	504,124	11,752,754
Overall change in PA	**1,548,000**	**1,863,000**	**13,800,000**	**1,404,000**	**74,530,000**

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