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Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia

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ABSTRACT

There are currently more than 700 cities operating bike share programs. Purported benefits of bike share include flexible mobility, physical activity, reduced congestion, emissions and fuel use. Implicit or explicit in the calculation of program benefits are assumptions regarding the modes of travel replaced by bike share journeys. This paper examines the degree to which car trips are replaced by bike share, through an examination of survey and trip data from bike share programs in Melbourne, Brisbane, Washington, D.C., London, and Minneapolis/St. Paul.

A secondary and unique component of this analysis examines motor vehicle support services required for bike share fleet rebalancing and maintenance. These two components are then combined to estimate bike share's overall contribution to changes in vehicle kilometers traveled.

The results indicate an estimated reduction in motor vehicle use due to bike share of approx. 90,000 km per annum in Melbourne and Minneapolis/St. Paul and 243,291 km for Washington, D.C. London's bike share program however recorded an additional 766,341 km in motor vehicle use. This was largely due to a low car mode substitution rate and substantial truck use for rebalancing of bicycles. As bike share programs mature, evaluation of their effectiveness in reducing car use may become increasingly important. Researchers can adapt the analytical approach proposed in this paper to assist in the evaluation of current and future bike share programs.

Introduction

As cities seek to improve sustainable transport options, bike share programs have emerged as an innovative approach in a growing number of cities in Europe, China and North America. There are now over 700 bike share programs in operation around the world (Meddin and DeMaio, 2014). These programs also serve to showcase and market eco-friendly mobility

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aspects of these cities, and may serve the stated mobility targets concerning health and fossil fuel dependence (Bachand-Marleau et al., 2012). Although bike share programs have existed for almost half a century, the most recent decade has seen a sharp increase in both their prevalence and popularity worldwide (Institute for Transportation & Development Policy, 2013; Larsen, 2013).

In 2007, Paris launched Europe's largest scheme, with over 20,000 bicycles. Wuhan and Hangzhou in China currently have the world's largest bike share programs, with 90,000 and 70,000 bikes respectively (Larsen, 2013). New York City launched North America's largest bike share program, with 6000 bikes in May, 2013, and is set to grow to 10,000 bikes in the near future.

Several researchers have examined the motivating factors associated with bike share 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 consistently emerges as the main motivating factor for bike share use, and this has been found in various programs in North America (LDA Consulting, 2012; Nice Ride Minnesota, 2010; Shaheen et al., 2012), China (Shaheen et al., 2011), London (Transport for London, 2011a) and Australia (Alta Bike Share, 2011; Fishman et al., 2012a, 2013a; Traffix Group, 2012). The distance between home and closest docking station is a factor directly associated with convenience and this has been found to be a reliable predictor of bike share usage. Bachand-Marleau et al. (2012) found that living within 500 m of a docking station resulted in a threefold increase in the odds of *BIXI* use. Similarly, Ogilvie and Goodman (2012) found London bike share members who lived close to docking stations used the system more than members living further away. In addition to convenience, *fun* appears to be a key motivation for casual users of London's bike share program (Transport for London, 2011b) and members of Washington, D.C.'s *Capital Bikeshare* program (LDA Consulting, 2013).

In 2010, Brisbane and Melbourne introduced bike share programs in their city centers and some of the local surrounding inner suburbs, known as *CityCycle* and *Melbourne Bike Share* (*MBS*) respectively. Bike share usage in Australia is considerably lower than other countries (Fishman, 2012; Fishman et al., 2012a, 2013a) and there are currently no commitments from other Australian cities to introduce bike share programs.

Shaheen et al. (2010) summarize the benefits of bike share as flexible mobility, emission reductions, physical activity benefits, reduced congestion and fuel use, individual financial savings and support for multimodal transport connections. Underlying many of the benefits attributed to bike share is an assumption that a significant proportion of bike share journeys are replacing trips previously made by car. International evidence suggests this is seldom the case (Fishman, 2012; Fishman et al., 2013a; Midgley, 2011). This paper seeks to examine net changes to car use as a consequence of bike share. It does this by examining estimated distance traveled and the degree to which bike share programs substitute for car use. A secondary component of this analysis examines motor vehicle support services used for fleet rebalancing and maintenance. Rebalancing refers to the practice whereby the operator runs special vehicles which drive around collecting bikes from stations that are at or close to capacity (full) and moving them to stations which are under stocked with bikes. Rebalancing requires fuel use and is not insignificant, and therefore this aspect of the ongoing operation of bike share programs must be considered. Rebalancing is not unique to bike share. Public transit vehicles run relatively empty in the contra-peak direction, in order to meet imbalances in demand across the network.

These two components are then combined to provide a picture of bike share's overall contribution to changes in vehicle kilometers traveled (VKT). The research question this paper seeks to address is '*what impact do bike share programs have on motor vehicle use*?'.

Whilst bike share's impact on car use is the focus of this paper, the authors do not wish to imply this is the only benefit of bike share. Potential benefits of bike share 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), as well as health benefits (Rojas-Rueda et al., 2011; Woodcock et al., 2014). Bike share programs may also ultimately encourage private bike use (Transport for London, 2011b) and assist in normalizing the image of cycling (Goodman et al., 2013) and this may have an important impact on reducing car use.

It is proposed that the analytical approach of this paper may be able to be adapted for future research evaluating bike share impacts.

Methodology

The cities included in this analysis are Melbourne, Brisbane, Washington, D.C., London, and Minneapolis/St. Paul (referred to in this paper as Minnesota, as the program is called *Nice Ride Minnesota*). The bike share programs included in this analysis have all been established in the past 5 years and are considered I.T based systems, relying on electronic payment and tracking technology, enabling automated rental and returns. The user can return the bike to any docking station within the system and it is this feature that creates the rebalancing responsibility for program operators.

The authors have obtained the data log for each of the bike share programs included in this analysis. This log contains information on each trip taken throughout 2012. Each system runs 365 days per year, with the exception of Minnesota, 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 2 min or greater than 3 h 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).

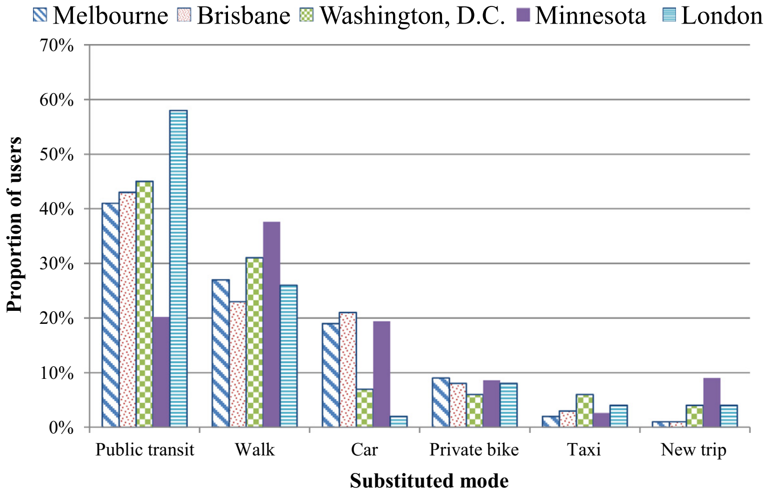

Fig. 1. Mode substitution in selected cities. *Source:* Melbourne and Brisbane (Fishman et al., 2013b), Washington, D.C. (LDA Consulting, 2012) Minnesota (Nice Ride Minnesota, 2010) London (Transport for London, 2011a).

Trip duration was determined by subtracting trip end time from trip start time. Distance traveled was estimated by combining trip duration with a travel speed estimate of 12 km/h, which is broadly consistent with a study on bike share travel velocity (Jensen et al., 2010). Only the proportion of trips substituting for car use has been included in the final analysis.

Motor vehicle fleet characteristics and usage for 2012 were obtained directly from bike share operators in Melbourne, Washington, D.C., London, and Minnesota. Brisbane bike share operator *JCDecaux* declined to provide data on this component of the analysis. Fuel consumed, type of fuel and fuel efficiency of vehicles allowed for the total distance traveled to be calculated for each system.

With many programs operating in the United States, the Washington, D.C. and Minnesota programs may not be representative of United States based bike share programs in general. Nevertheless, 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.

Results and discussion

Mode substitution

The members of the bike share 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 bike share, which mode of transport would you have taken had it not existed*?"[3] These surveys were conducted as independent activities and carried out or commissioned by the operators of each program. *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 (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 *MBS* and *CityCycle* members. Fig. 1 documents the results to this question, across the aforementioned bike share programs.

A substantial proportion of trips currently taken on bike share in the cities included in this study are substituting for public transit and walking, which is consistent with a study of the Montreal bike share program known a *BIXI* (Fuller et al., 2013). 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 substantial proportion of bike share trips substituting for public transit, particularly in London, may be helping to relieve public transit overcrowding.

Bike share fleet size, usage and car travel reduction

Table 1 presents the key metrics used to estimate the reduction in car travel as a consequence of the bike share programs. The number of trips per day per bike provides an opportunity to compare different systems usage levels, controlling for fleet size. London and Washington, D.C. have the largest number of bikes, total trips and most trips per bike.

[3] 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"* ($n = 5287$). In Minnesota: *"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*?" ($n = 2177$).

Table 1
Bike share size, usage and car travel reduction.

	Melbourne	Brisbane	Washington, D.C.	Minnesota	London*
Bikes[a]	600	1800	1800	1325	8000
Trips[b] (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
Regional population[2]	3,999,980	2,065,998	5,860,342	3,759,978	7,170,000
Mean trip duration[b]	22.0	16.2	15.8	17.5	17.5
Est. travel speed (km/h)	12	12	12	12	12
Est. distance traveled per trip (KM)	4.4	3.2	3.1	3.5	3.5
Est. distance traveled per system 2012 (KM)	609,611	677,912	6,345,530	940,152	31,642,029
Car substitution	19%	21%	7%	19%	2%
Est. car travel reduction (KM)	115,826	142,361	444,187	182,390	632,841
Est. car travel reduction per bike (KM)	193	79	247	135	79
Annual members	921	1926	18,000	3500	76,283

Source: Regional population: Brisbane and Melbourne (Australian Bureau of Statistics, 2013), London (Greater London Authority, 2012), Minnesota (Minneapolis/St. Paul Combined Statistical Area) (Wikipedia, 2013) and Washington, Metropolitan Area. (Wikipedia, 2012). Trips and duration: Melbourne (Hoernel, Unpublished data), Brisbane (Lundberg, Unpublished data), Minnesota (Vars, Unpublished data), London (Stanhope, Unpublished data), Washington, D.C. (Capital Bikeshare, 2013), Estimated travel speed (Jensen et al., 2010). Car substitution (Fishman et al., 2013a)

[a] Fleet total, which may not reflect actual number of bicycles in circulation.

[b] Trips < 2 min and > 3 h excluded from analysis.

* In March 2012, London's bike share fleet rose from approximately 6000 bikes to 8000 bikes. Serco (bike share 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 min duration removed by Serco between 29th April – 18th August 2012 (unrecoverable).

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

Table 1 demonstrates the impact *car substitution* has on *estimated car travel reduction*. Car travel reduction has been estimated by multiplying the estimated distance traveled by the car substitution rate. Our analysis shows that for 2012, bike share usage was responsible for 115,826 km less car driving in Melbourne, through to 632,841 km less car use in London. Washington, D.C. despite having almost ten times greater bike share travel than Brisbane, only has approx. 3.5 times the car use reduction impact. This difference is due to a *car substitution* rate of 21% for Brisbane, compared to only 7% for Washington, D.C.

In addition to the results presented above, which use a bicycle speed of 12 km/h, a sensitivity analysis was performed, to determine the impact at speeds of 10 and 14 km/h. Naturally, a shift in average bike speed from 12 to 10 km/h reduces estimated car travel reduction by 20%, whilst a rise to 14 km/h as the average bike speed increase distance traveled by 20%. This sensitivity analysis has also been used in Section 'Bike share impacts on vehicle kilometers traveled' to show its impact on overall changes in VKT.

Bike share operator motor vehicle usage

A challenge for many bike share operators has been the rebalancing of bicycles, to reduce the likelihood of docking stations being either completely empty or full (Midgley, 2011). Fleet rebalancing is typically achieved through the use of trucks and trailers, and these are associated with many of the very impacts bike share aims to reduce (e.g. congestion, pollution). Table 2 provides an indication of the fuel used and distance traveled for the cities included in this analysis.

Bike share impacts on vehicle kilometers traveled

By comparing estimates of car travel reduction as a consequence of bike share (Table 1) with motor vehicle use associated with the operation of bike share (Table 2), it is possible to estimate the net effect of bike share on VKT. Fig. 2 indicates that for each kilometer traveled by motorized vehicles associated with the operation of bike share programs, there are between 2 and 4 km of private car use avoided, with the exception of London, in which the relationship is reversed.

Table 2
Fuel consumption of bike share operators' vehicles, 2012.

City	Annual distance traveled (KM)	Diesel consumed (liters)	Unleaded petrol consumed (liters)	CO_2 emissions (Tons)[a]
London	1,399,182	116,605	391	316
Minnesota	88,000	–	11,436	26
Melbourne	27,851	2,952	–	8
Washington, D.C.	200,896	23,765	–	64

Source: London (Stanhope, Unpublished data), Minnesota (Vars, Unpublished data), Melbourne (Hoernel, Unpublished data), Washington, D.C. (Fisk, Unpublished data).

NB: Washington, D.C. fuel use is for the period September 2011 to September 2012. An additional vehicle was added to the fleet in October 2012 and this has been included in the calculations. London data for fourth quarter fuel usage not available. Third quarter data was substituted.

[a] 2.3 and 2.7 kg of CO_2 for each liter of petrol and diesel consumed respectively (Commonwealth of Australia, 2013).

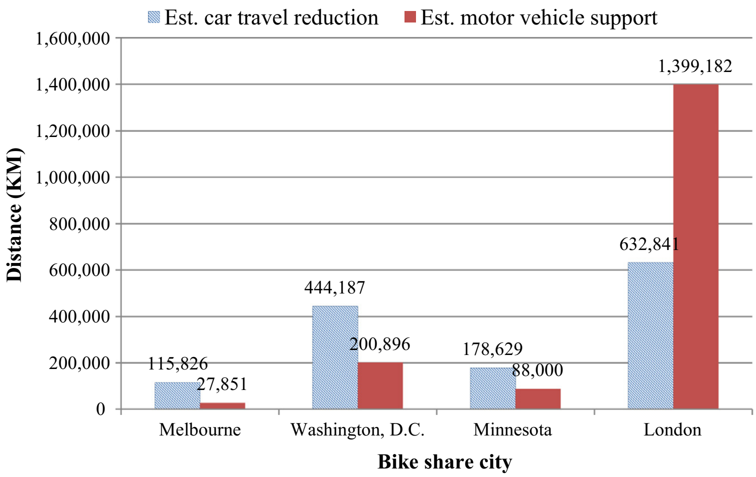

Fig. 2. Comparing car use reduction to motor vehicle support, selected cities, 2012.

London, owing to its car mode substitution rate of only 2%, coupled with heavy demand for fleet redistribution is estimated to have approximately 2.2 km in motor vehicle support travel for each kilometer of private car use avoided. An unusually strong 'tidal' commuter pattern, possibly caused by heavily demarcated residential and commercial zones may have contributed to the significantly greater distance covered by the London bike share operator, even after accounting for the larger number of bicycles.

To illustrate the influence of mode substitution, should the percentage of bike share trips substituting for car increase to 10% in London, estimated car travel reduction would rise to 3.1 million km, approximately 2.2 times greater than the distance travelled by motor vehicle support services. Nevertheless, even in the current analysis, London's bike share program still accounts for the greatest replacement of motor vehicle travel (632,841 km) and underlies the significant potential large scale bike share programs have for reducing car use.

The sensitivity analysis introduced in Section 'Bike share fleet size, usage and car travel reduction' regarding changes to average bike share speeds has also been performed. Reducing average speeds to 10 km/h had a small reduction on the net change to VKT, whilst an increase to 14 km/h brought a larger reduction in car use.

When all cities are combined, the results of this analysis show an overall *increase* in motor vehicle use as a consequence of bike share (i.e. more kilometers are traveled by bike share operator support vehicles than bike share travel substitutes for car use). At a bike speed of 12 km/h, this amounts to an *extra* 344,446 km of motor vehicle travel when all cities are combined. However, this result is strongly skewed by London, which, as described above recorded substantially higher fleet redistribution travel, even when controlling for the size of its bike fleet. When London is removed from the analysis, and only Melbourne, Washington, D.C. and Minnesota are included, the overall impact of bike share on motor vehicle use is a *reduction* of 421,895 km in motor vehicle use.

Optimizing car use reduction

The analysis presented above offers a counterintuitive finding; bike share programs can lead to an overall *increase* in motor vehicle use. As previously highlighted, the impact of bike share on car use is determined to a large degree by the rate of car substitution.

When comparing the commute transport patterns for each of the cities included in this analysis, two groups can be distinguished; high and low car use cities. According to Census data, Brisbane, Melbourne and Minneapolis have between 70% and 76% of residents travel to work by car (Australian Bureau of Statistics, 2013; United States Census Bureau, 2013). These cities also have relatively high rates of car mode substitution, with between 19% and 21% of bike share users replacing trips that would have previously been made by car. In London and Washington, D.C. however, only 36% and 46% of residents respectively travel to work by car (Transport for London, 2011b; United States Census Bureau, 2014) and their bike share programs only record a car mode substitution rate of 2% and 7% respectively. Thus, based on the analysis conducted in this paper, a relationship is apparent, in which the higher the commuting car use, the greater the bike share system replaces car use. One possible explanation for this relationship is that for a city such as London, car use is already rather inconvenient and many people who could choose an alternative have, making it more difficult for bike share to attract new trips from car users.

It is plausible that there are many underlying reasons for different mode substitution rates, such as density and access to public transit. London and Washington, D.C. have substantially higher population densities than the other cities included in this analysis (Demographia, 2014). Further research is required to determine the presence and strength of these and other potential explanatory factors for different car mode substitution rates.

Barriers to bike share can broadly be divided into two categories; those acting as barriers to bike use generally, such as safety concerns or distance, and secondly, those relating specifically to bike share, such as docking station location. Previous research shows *convenience* factors to be one of the most important motivators for bike share use (Fishman et al., 2013a; LDA Consulting, 2012, 2013; Shaheen et al., 2012). Moreover, safety concerns have been shown to be a key barrier to biking in both the UK, US (Horton et al., 2007) and Australia (Fishman et al., 2012b).

Limitations

Although every reasonable action has been taken to ensure the validity of the results, several limitations have been identified. Trip usage data may contain technical errors, although this has been mitigated by omitting all journeys recorded as being below 2 min or greater than 180 min duration. Such trips are likely to be the result of user or technical error rather than a genuine trip. An assumption has been made that bike share trip length is the same as a substituted car trip. Data from Lyon suggests bike share trips may be 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 group in all cities included in Fig. 1 are annual bike share members, as distinct from casual users. It is plausible casual members may differ in their mode substitution pattern and previous research from Washington, D.C. (Virginia Tech, 2012) and Montreal (Morency et al., 2011) has identified differences between annual and casual users. Casual users may be more likely to use bike share for touristic purposes and less likely to be replacing a motor vehicle journey. Future research on mode substitution may benefit from differentiating the question by weekday/weekend, as well as whether car trips substituted were single-occupancy or higher.

Motorized vehicle fleet data were provided by the bike share operators and have not been independently audited. London's disproportionately greater levels of motor vehicle support is difficult to reconcile, given that it is seven times greater than Washington, D.C. system, but has only 4.4 times more bikes. Including other large-scale bike share systems in future analyses may provide further insights into the fleet redistribution requirements of major bike share programs. It should be noted that the mileage of vehicles (fuel used per unit of distance traveled) used by bike share operators is likely to be significantly more than the typical private car and therefore caution should be exercised when comparing the two.

Conclusions

Bike share has emerged as an initiative to expand sustainable transport opportunities in predominately urban settings. The number of bike share programs has grown dramatically over the past 10 years, particularly in North America, Europe and China. An implicit assumption that equates bike share use with car use reduction has emerged, despite evidence showing that only a minority of bike share journeys are replacing car trips (ranging from 2% in London to 21% in Brisbane).

This paper has used ridership and mode substitution data from bike share programs in Melbourne, Brisbane, Washington, D.C., London, and Minnesota to better understand the magnitude of changes to car use as a consequence of bike share programs. This type of analysis revealed the critical importance of car substitution rates to bike share's car use reduction impacts. The greater the proportion of trips substituting for those previously made by car, the greater the program's impact on reducing car use and all of the associated benefits. Understanding barriers to bike share from those who predominantly drive may assist efforts to increase the rate at which bike share substitutes for car use.

Pressure on bike share operators to maintain a reasonably balanced system requires a reliance on motorized trucks and vans to re-distribute bicycles to different docking stations throughout the day. This paper compares the reduction in car use as a consequence of bike share with the VKT of program operators for fleet redistribution and maintenance. According to the findings, when all cities included in this analysis are combined, there is 344,446 km *more* travel by motor vehicle support services then the VKT avoided when bike share replaces car use. This finding is due to the London results, which showed a much larger level of motor vehicle support than private car use avoided. The other cities showed approximately twice the car use avoided compared to the distance traveled by motor vehicle support services. Should London's car mode substitution rate increase from its current 2% to 10%, it is estimated the reduction in VKT to be approximately twice the distance travelled by operational and maintenance vehicles. Future research focused on innovative techniques to minimize manual redistribution by conventional motorized vehicles will improve the efficiency and sustainability credentials of bike share operators.

The results of this paper demonstrate that in order for bike share programs to optimize their impact on reducing car use, it is necessary to implement measures focused on encouraging a mode shift from car to bike share.

Finally, this paper has provided the foundational elements for evaluating the impacts of bike share on travel patterns and outcomes related to fuel use, emissions, congestion and physical activity. Researchers can adapt the analytical approach proposed in this paper to assist in the evaluation of current and future bike share programs.

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