AN EVALUATION FRAMEWORK FOR ASSESSING THE IMPACT OF PUBLIC BICYCLE SHARE SCHEMES

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Date submitted
28th July 2011

Word Count:
6,023 + 1 table = 6,273 words

ABSTRACT

In an effort to address a number of public policy challenges, federal, state and local governments have begun to encourage bicycle riding for transport. When used as a substitute for motor vehicle use, cycling reduces traffic congestion and carbon emissions, and provides a practical source of physical activity, helping to reduce diseases associated with a sedentary lifestyle, such as diabetes. An increasing number of cities are operating public bicycle share schemes (PBSS) to promote greater levels of bicycle riding. This rapid expansion of PBSS, however, has occurred in the absence of a comprehensive evaluation framework to properly assess their effectiveness and impact. The absence of such a framework hinders thoughtful, consistent analysis and constrains the ability to reliably quantify the potential broad ranging impacts of these schemes. Moreover, identifying the determinants and detractors of success of PBSS is an important goal that is greatly assisted by the establishment of an evaluation framework.

This paper provides a critical review of the most recent literature on PBSS and identifies substantial gaps in current knowledge. Addressing the gaps, the first conceptual evaluation framework within which the effectiveness of PBSS can be assessed is presented. The framework brings together essential analytical elements required to quantify and assess how PBSS are performing. Using Barcelona's PBSS as a case study, this paper provides a practical conceptual basis for improving our understanding of how to measure the impact of these increasingly popular PBSS on transport, sustainability, health, and community livability objectives.

INTRODUCTION

Governments have begun to encourage bicycle riding for transport, in an effort to address a number of public policy challenges. Cycling, when used as a substitute for motor vehicle use reduces traffic congestion and carbon emissions, and provides a practical source of physical activity, helping to reduce diseases associated with a sedentary lifestyle, such as diabetes *[1-3]*. In recent years PBSS have emerged to promote increased bicycle riding. What initially began as small pilot projects in some Northern European cities in the 1960s, have expanded into large-scale, city-wide schemes in many European cities, as well as similar, albeit typically smaller programs in the US, Canada and Australia. Hangzhou, China currently has the largest bicycle program globally, with over 60,000 bicycles *[4, 5]*. The overwhelming majority of the growth in PBSS has taken place since 2005, due to increased public policy focus on bicycle riding and various tracking and payment technologies becoming available and affordable *[6]*.

Contemporary PBSS refer to the provision of bicycles to enable short-term rental from one docking station (where bicycles are picked up and returned) to another. These bicycles usually contain technologies that allow operators to track their location. Members of the public are able to register to hire the bicycles, either online or through information kiosks, although some schemes only allow online registration. These kiosks are generally located at each docking station. Pricing structures typically encourage short-term rental (for example, the first 30 minutes are usually free), after which users are typically charged on a sharply rising scale. Users are generally required to provide credit card details, which act as both a deposit and payment for registration and usage fees.

Over the last 10 to 15 years, a range of government programs have served to promote cycling and these can be broadly divided into *'soft'* and *'hard'* measures *[7]*. Soft measures refer to social marketing campaigns focused on providing information to encourage a shift from single occupant car use towards more sustainable transport options, such as car pooling, walking, cycling, public transport and telecommuting. Hard measures relate to changes in the built environment that support walking, cycling and public transport (e.g. bicycle paths). Public bicycle share schemes contain elements of both these approaches, as they require significant promotional campaigns, as well as the provision of infrastructure (bicycles, docking stations and signage).

Although the rapid growth of PBSS is encouraging from a sustainable transport perspective, very little research has been undertaken to determine their potentially broad impact on transport behavior and consequently, it is difficult to understand the performance of PBSS in terms of reduced emissions and congestion, as well as possible increases in physical activity.

This paper builds on current knowledge by describing for the first time an evaluation framework for measuring the overall performance of PBSS. This framework will provide, through future work, the ability to identify and measure the relative importance of factors affecting the level of success of PBSS. These factors, such as location of docking stations, number and availability of bicycles, relative attractiveness as a travel mode, extent of complementary bicycle infrastructure, and safety concerns will be addressed in a separate paper as a result of implementing this proposed framework.

LITERATURE ON PUBLIC BICYCLE SCHEMES

Public bicycle share schemes have existed for almost 50 years, although the last decade has seen a sharp increase in both their prevalence and popularity, as illustrated recently by Shaheen et al. *[6]*. In their overview of the state of PBSS globally, Shaheen et al. *[6]* provide data on the size of various systems, but the current pace of activity is such that published statistics rapidly become outdated. For instance, Washington D.C. is quoted as having 120 public bikes in 2010 and whilst this was accurate at the time of publication, a new system has since been established, Capital Bikeshare (CaBi), with 1,112 bicycles *[8]*.

Shaheen et al. *[6]* summarize the benefits as:

- Emission reductions
- Reduced congestion and fuel use
- Flexible mobility
- Individual financial savings
- Health benefits
- Support for multimodal transport connections, by acting as a *'last mile'* connection to public transport.

Implicit in the first two listed benefits is the assumption that a significant proportion of users are transferring to public bicycle from single occupant car use. Research from China indicates that a large proportion (around 80%) of those using PBSS would have otherwise walked, used public transit, or traveled on their own bicycle if the PBSS was not available *[9]*. Given the low level of car use in Chinese cities relative to the West, it is not surprising that there have been modest shifts from car users towards PBSS; however, the sheer magnitude of some of the Chinese schemes may translate to significant impacts.

Modal share changes occurring in Western PBSS are of key interest, given the expressed need to decrease the level of private motor vehicle use in these cities. A recent study of the Dublin scheme *[10]* found that 15% of users would not have made the trip had it not been for the PBSS. Of those changing modes, 66% had previously walked, 7% shifted from private car, 14% previously rode public transit and 11% migrated from private bicycles. Confirming a view commonly expressed in the literature, Murphy found that 55% of PBSS users are chaining trips. Walking was the most common linking mode, with 42% of the 55% indicating they walked more than 500m in combination with bicycle share use. The overwhelming majority of users of the Dublin scheme (70%) state their trip purpose to be work or education related *[10]*. In Minnesota, 57.8% of PBSS users would have walked or took public transit if the scheme had not been available. Almost 20% indicated they would have driven a car and 8.3% would have used their own bicycle *[11]*. This study offers a useful comparison to the literature on Chinese PBSS, as it provides an illustration of the differences in modal shift when a PBSS operates in a car dependent country.

Previous evaluations of public bicycle share schemes

Public bicycle share schemes received international prominence in 2007, after Paris and Barcelona both introduced large-scale systems *[12]* and as such, it is an emerging area of research interest. Although few peer reviewed papers have directly addressed the evaluation of PBSS, the following section provides an overview of the research that has at least briefly explored evaluation issues.

Montreal, Canada was the first large city in North America to establish a PBSS, known as BIXI, which combines the words 'bicycle' and 'taxi'. BIXI started in 2009, with 5000 bicycles at 450 docking stations *[13]*. Fuller et al. *[13]*, focusing on the BIXI scheme, investigated the prevalence and correlates of using public bikes among Montreal residents. The investigation conducted telephone surveys with 2502 people to compare the prevalence of using the scheme depending on whether the respondent lived within 250m of at least one docking station. The authors found that for those living within 250m of a docking station, 14.3% had used BIXI, whereas only 6% had when living greater than 250m of a docking station. Almost 80% of respondents live beyond 250m of a docking station, with 12.8% living within 250m of one docking station and 7.9% having more than one docking station within 250m. Other correlates of use included being between 18 - 24 years, having a tertiary education, being on occupational leave and using a private bicycle as a mode of transport for work. According to the findings of this research, users are more likely to ride private bicycles, potentially conflicting with the primary purpose of PBSS to increase the proportion of the population riding bicycles. Interestingly, men and women had the same likelihood of using BIXI, in contrast to the higher proportion of males among non-PBSS male bicycle riders in North America *[14]*, and Australia *[15]*. Whilst an interesting and useful addition to the body of research on PBSS, this study had several limitations including a failure to ask respondents questions on car ownership, substituted mode and distance traveled. Including such questions would have more effectively captured the full possibilities for new knowledge in this area.

Yang et al. *[9]* compared the PBSS of Beijing, Shanghai and Hangzhou, as well as investigated the impact these systems had on transport patterns. The data were collected via a survey of users (154 respondents in Beijing, 218 in Shanghai and 276 in Hangzhou) who were asked a range of questions regarding their transport choice. Significant differences in trip purpose were found across the three cities. In Beijing, almost 45% of respondents reported using the public bicycles for journeys to work, compared to around 18% for both Shanghai and Hangzhou. Over half the Shanghai respondents reported using PBSS for the return from work journey, compared to 29% and 23% for Beijing and Hangzhou respectively. Hangzhou respondents generally used the bicycles for a broader range of trip purposes than Beijing and Shanghai respondents. Although the researchers made it clear what time of year the survey was undertaken (September), it was unclear what time of day the survey questions were asked, and this may have had an impact on responses, given that respondents were only able to select one journey purpose.

Yang et al. *[9]* found integration to the metro system to be an important function of the PBSS in both Beijing and Shanghai, with 58.4% and 55% of respondents combining these modes respectively. Hangzhou's metro system is currently under construction, but an extensive bus network services the city, with passengers provided an extra 30 minutes on the public bicycles before incurring a fee (90 minute free period instead of 60 minutes). In terms of the reasons for using the PBSS, saving time and money appear to be the key reasons. Interestingly, 60% - 70% of respondents reported that using the PBSS was a more convenient option than using private bicycles.

An important element in Yang et al. *[9]* paper is their investigation of mode substitution, that is, what modes of transport would people use had it not been for the PBSS. This is a key determinant of the impact PBSS have on transport, the environment and livability, as it illustrates the shift from private motor vehicle use to public bicycle. Given the low proportion of trips in China by private motor vehicle, it is not surprising that only 5.2%, 0.46% and 4% of bicycle trips were substituting for private car in Beijing, Shanghai and Hangzhou respectively. The authors conclude that the shift from private motor vehicle has been disappointing. Indeed, the overwhelming substitution came from walking and public transit. The survey design was limited, as it did not collect information on trip distance, including any variation between the trip distance of the public bicycle journey and the mode that would have been used had the PBSS not been available. Trip distance is a key determinant of congestion, emissions, impact on livability and physical activity [7, 16, 17]. Also missing from the evaluation were the number of trips per day per bicycle, as this would, in combination with average trip distance, provide an aggregate measure of total distance traveled by public bicycle. Moreover, total number of subscribers and the percentage of trips that are *'new'* (would not have otherwise been taken) were important but absent components of the study. Despite these limitations, Yang et al. *[9]* have made an important contribution to the literature and a useful foundation for further work.

Shaheen et al. *[18]* recently undertook one of the most detailed investigations to date into PBSS. The authors sought to better understand the travel impacts of the world's largest PBSS, in Hangzhou, China. Bicycle modal share in Hangzhou, whilst significantly reduced from two decades ago, still hovers at 33.5% [9], which is comparable to the highest bicycle modal share in European cities [19]. The researchers conducted intercept surveys with members and non-members of the PBSS, all in close proximity to docking stations. A key aim of the study was to determine how the PBSS influenced transport choice. Over 800 surveys were completed, the vast majority of respondents being members of the PBSS. The researchers asked the respondents what mode of transport they would have used had the bicycle scheme not existed. The results reveal the following shifts in mode share as a consequence of the PBSS:

- An overwhelming majority previously walked or used the bus. In fact for non-car owners, 80% shifted from public transport, compared to 50% for car owners.
- 30% shifted from taxi to bike share.
- Almost four out of five (78%) of the car owners said they used bike share for trips they would have ordinarily have used the car.

In terms of PBSS use during peak hour, 70% of members said they use the bikes '*at least occasionally*' and 30% said they did so '*regularly*'. This provides an indication of the impact the PBSS have on congestion and something missing from previous evaluations. The authors found '*...car ownership does not lead to a reduced propensity to use bike sharing. In fact, members exhibited a higher rate of auto ownership in comparison to non members*' (p. 13). This may well be a result somewhat unique to China, in which early adopters of bike sharing were also more willing to purchase a motor vehicle.

Amongst non-members, those classified as "persistent" non-members (not members and not interested in becoming members); only 20% reported using their bicycle for work purposes, rising to 30% for '*potential*' members. In terms of bicycle ownership, there were an average of 0.55 bicycles per household for members and 0.49 for non-members. This is noteworthy, as it means that the notion of owning a bicycle would make you *less* interested in bike sharing is invalid. This confirms a theme throughout the literature – PBSS members have a greater propensity to cycle independently of PBSS.

Distance traveled was not collected as part of the survey (either for the previous mode of transport, or the public bicycle trip). The authors are therefore unable to provide a quantitative assessment of the key measures PBSS are proposed to improve (congestion/ emissions/physical activity). Nevertheless, the authors established a comprehensive knowledge base, particularly with regard to mode substitution, that will serve as a foundation for future research.

Gaps in the literature

The literature on PBSS is consistent in noting the lack of evaluation on the impact of PBSS on transport behaviour *[6, 9]*. Shaheen et al. *[6]* identify that some PBSS providers have calculated estimates of the reduction in greenhouse gas (GHG) emissions based on the number of kilometers their bicycles travel. It is important to qualify these claims, as it assumes the riders would have been driving a motor vehicle as a single occupant, despite evidence to the contrary *[10, 11, 18, 20]*. There is limited knowledge of who uses PBSS, what mode of transport they would have used if the scheme did not exist, and whether it generates trips that would not have otherwise occurred. Even in the few studies that have investigated these factors, distance traveled is often omitted, and as a consequence, it is difficult to calculate key measures of success, such as reductions in GHG emissions and congestion or increases in physical activity. Urban livability improvements, although more difficult to measure, are an important component of any evaluation of the impact of PBSS, given that livability is often a key driver for such programs *[12]*. The paucity of research investigating the direct impact and evaluation of PBSS serves as the impetus for this research.

A number of indirect impacts of PBSS are yet to be addressed in the literature. For instance, the potential for PBSS to *legitimize* bicycle riding has not been evaluated. Research conducted for the UK Department for Transport has previously found drivers to be frustrated with cyclists, viewing them as an *out-group [21]*. Public bicycle share schemes, as a prominent action by government to support bicycle riding, may act to increase the level of legitimacy of bicycle riding. Finally, little research has focused on the perceptions, attitudes and preferences of those who don't ride a bicycle. Improved understanding of this group, especially those who drive as their primary mode of transport may help shift car journeys to PBSS.

PROPOSED EVALUATION METHODOLOGY

The goal of the evaluation framework proposed here is to postulate a set of measureable PBSS system attributes that can be used to evaluate a single program across time and compare the performance of PBSS across jurisdictions and countries. It is a broad evaluation framework that does not seek answers to questions about why they perform as they do, but rather simply to provide a measuring stick that can be applied across programs.

In order to measure the impacts of PBSS fairly and accurately across systems, it is necessary to measure a consistent set of variables; for example, kilometers transferred from car driver to public bike (see Table 1 for a comprehensive list). These variables provide a reliable indication of how the PBSS meet public policy goals in terms of congestion, climate change and physical activity. Table 1 below identifies key variables this paper proposes to use in the evaluation framework. The intention is that by collecting data on these variables from the responsible PBSS operator and/or a third party (including previous studies), the necessary inputs to an evaluation framework will be identified. For the purposes of this paper, inputs are data providing the quantitative basis for deriving estimates of the performance of PBSS. The number of bicycles and the kilometers traveled on the system each day are examples of inputs. Outputs are the estimates of PBSS performance based on the inputs, such as carbon dioxide abatement and physical activity impact.

By assessing these variables in combination with values derived from recent literature measuring the economic benefits of walking and cycling *[16, 17]*, it has been possible to calculate an economic benefit associated with PBSS use. The values applied to the economic impact of increases in bicycle riding and reductions in motor vehicle use are based largely on a meta analysis of work completed in Europe, the UK, the US, New Zealand and Australia that have attempted to monetize the various costs and benefits associated with changes from motorized to active forms of travel [17]. The purpose of monetizing the benefits associated with PBSS is that once combined with *costs*, it will be possible to undertake a benefit-cost analysis, used to determine a benefit-cost ratio (BCR). Benefit-cost ratios are increasingly used in project planning and evaluation [16]. As Barcelona's PBSS is the only system for which the authors have been able to determine a complete dataset on key variables, accessed through publicly available reports [22-25], we have applied our evaluation framework for this city, as a case study.

In addition to the information contained in Table 1, it may also be necessary to ascertain the trip distance of participants' previous mode of transport. It is plausible that when using a public bicycle for a trip that has a degree of flexibility (such as visiting shops), the trip is shorter than had the trip been undertaken by public transport or private motor vehicle *[26]*. Conversely, the PBSS journeys that replace walking trips may be longer than if the trip had have been conducted by foot alone, as the faster traveling speed may favor a competing destination further field. Clearly this will not be the case for commuting and other trips with a fixed destination.

TABLE 1 Conceptual Evaluation Framework

Variable[#]	Barcelona PBSS
Inputs	
Number of bicycles	6000
Number of docking stations	420
Trips per day per bike	5 - 6
Kilometers per day	30,546
Percentage of trips occurring in peak hour^	20.00%
% Substitute mode public transit	55.10%
% Substitute mode motor vehicle	9.60%
% Substitute mode walking	26.10%
% Substitute mode private bike	6.30%
% Substitute mode taxi	NA
% New trip	2.80%
Health benefit for walking (per kilometer)*	$1.56
Health benefit for cycling (per kilometer)*	$0.78
Congestion reduction benefit (per kilometer)*	$0.34
Climate change benefit (per kilometer)*	$0.02
Outputs	
Congestion benefit per day*	$199.40
Climate change benefit per day	$58.65
Physical activity benefit per day	$3,645.36

1 kilometer = 0.621 miles.
[#]*All values unless otherwise noted are sourced from the City of Barcelona [25] and Anaya [22] with substitution mode figures collected in 2007.*
^An estimate made by Elliot Fishman
**Values derived by Ker et al. [17] for the Queensland Government. These values are based on the Australian context and it is likely these values will need to be adjusted for use in other countries, owing to variations in congestion, carbon price and population health. Australian dollars have been used, which are at approximate parity with the US Dollar at the time of publication.*

The health benefit values used in Table 1 were recently developed for the Queensland Government, Australia *[17]*.

Collecting data on the input variables contained in Table 1 provides the base level information on which to judge the impacts of PBSS. Combining these data with recently completed research measuring the monetized benefits of walking and cycling *[16, 17]*, an assessment of the economic benefits of PBSS can be illustrated, with a focus on the key policy goals: congestion, climate change and physical activity. These metrics have been used due to the availability of monetized values and their association with the typically stated goals of PBSS, namely, their proposed ability to reduce congestion and greenhouse gas emissions, as well as their ability to encourage physical activity.

When motor vehicles travel at peak hour they contribute to congestion. The *congestion* benefit associated with PBSS is derived by determining the kilometers not traveled by car (as driver) at peak hour due to the PBSS. The impact on *climate change* has been calculated using the number of kilometers substituted from car travel (as driver) due to PBSS. The *physical activity* benefit was determined by calculating the kilometers traveled by PBSS that would have been undertaken by public transit, motor vehicle, as well as new trips. This was multiplied by the $/kilometer health benefit of cycling. This was then subtracted by the health benefit of walking 'lost' due to the transfer of pedestrian trips to PBSS. It is noted that walking has double the physical activity health benefit of cycling, on a per kilometer basis *[16, 17]*.

A number of assumptions have been made when constructing Table 1. Firstly, when measuring the congestion benefit, only single occupant private motor vehicle (car) travel that was replaced by PBSS was included, as motorbike/scooter, walking and public transport do not add to conventionally measured traffic congestion. An assumption that 20% of PBSS use occurred at peak hour was made. Similarly, the impact PBSS have on greenhouse gas mitigation has only included PBSS journeys that replace car travel (as a single occupant). Moreover, when calculating the impact of physical activity, it is important to consider the amount of walking that PBSS replace, given that evidence to date demonstrates that a large proportion of PBSS trips are replacing trips previously completed by foot. Finally, the cost of PBSS will vary, and may need to be calculated to justify expenditures, in a similar manner to public transit, notwithstanding the fact that public transit often operates as a subsidized service.

DISCUSSION

By outlining some of the key components crucial to measuring the performance of PBSS, the proposed evaluation framework demonstrates how variables can be translated back to the public policy motivations behind PBSS – in terms of climate change, traffic congestion and physical activity. Using Barcelona's PBSS as a case study, the conceptual evaluation found that increases in physical activity account for over 90% of the benefit associated with the PBSS. Climate change, whilst generally considered one of the key motivating factors behind PBSS, had only minor benefit, although this was at a carbon price of $20/tonne. The congestion benefit is likely to be underestimated, as some congestion occurs outside of peak hour and this was not included in our calculations.

Based on the stated benefits of PBSS outlined by Shaheen et al. *[6]*, future evaluation frameworks might include measures of how PBSS support multimodal integration and time and cost savings for users. These outcomes are currently difficult to measure given the paucity of literature in this area, particularly for systems in North America and Australia, and will be investigated in components of this team's future research.

A key factor determining the success of PBSS is the degree to which the public bike trip is replacing a car journey (as driver). No material in the peer reviewed literature is available on this issue for North American and Australia. Of the little research that has been conducted, mostly in Europe and China, it appears only a small proportion of journeys on PBSS are replacing trips that would have been done by car, as driver. A recent survey of members of the London PBSS found only 1% reported they would have driven a car, had the PBSS not been available *[20]*. Typically, 50 - 80% of PBSS users globally are transferring from public transit, walking or private bicycle.

The framework proposed here is meant to serve as a starting point for standardizing how PBSS are evaluated, and to energize discussions surrounding PBSS and their measurement. It will also serve to facilitate a deeper investigation into what other factors influence the outcomes of PBSS, and how they should be measured and understood. It is also likely that the evaluation framework itself will evolve as this discussion continues, and as methods for identifying and measuring costs and benefits are determined.

Additional issues for further study

The proposed evaluation framework is limited in the number of variables it considers. With almost all PBSS still in their infancy, and given the lack of previous research developing evaluation tools, the proposed framework only includes relatively objective, quantifiable outputs. In part this is due to the limited data available. Measures of livability, impacts on road safety, costs of vandalism/theft and influences on private bicycle riding have not been included in the framework. Despite these limitations, the proposed framework offers a useful foundation upon which to evaluate PBSS performance against their purported attributes and across jurisdictions.

This paper does not investigate the factors affecting the performance of PBSS. This work will be carried out through a series of consumer preference surveys in subsequent research by the authors.

It is beyond the scope of this paper to include the costs associated with PBSS, in terms of the provision of bicycles, docking stations, signage, redistribution and administrative/promotional expenses. First, these costs are not straightforward to calculate, as the costs can be shared across agencies and leveraged by private industry investment, for example advertising dollars. In addition, there is considerable capital intensive investment (e.g. consider building a road) for which any PBSS must operate for a considerable length of time to recoup initial costs. Since most programs are fairly new, these initial costs will dominate the assessment at this stage. However, it is acknowledged that in public policy forums the costs of such programs will necessarily rise to the forefront. Accounting for the costs of programs will remain a topic of future research.

Despite the attempt to provide a stable platform upon which to assess PBSS, a number of less quantifiable but potentially significant variables remain outside of the proposed evaluation framework and will require thoughtful research. Firstly, whether implicitly or explicitly stated by the sponsoring authority (usually government), PBSS provide an additional transport *choice*, and this choice (whether or not it is taken up by the individual) may have value. Related to this value is the perception of benefit PBSS offer the city, in terms of community cohesion, environmental awareness and international status. Whilst the literature has not begun to explore these factors, there is anecdotal evidence *[27]*, suggesting further research in this direction may be warranted .

Secondly, public transit has a significant walking component *[28]* and the walking involved in public transit journeys that has been replaced by PBSS has not been included within the calculations contained in Table 1. As improved information regarding travel modes substituted by PBSS becomes available, it will be possible to include the walking component of public transit journeys within the evaluation framework. Moreover, our literature review failed to find any studies that investigated the physical activity levels of those using PBSS and if their physical activity habits altered upon joining the PBSS. This is important given that attributing a health value to the use of PBSS is determined in part by the quantity of physical activity that is already undertaken and whether the PBSS replaces physical activity that was previously undertaken.

There is a possibility that PBSS may have a variety of traffic congestion impacts beyond the $/kilometer value associated with reductions in motor vehicle driver journeys (contained in Table 1). Public bicycles, whilst generally seen as an opportunity to reduce traffic congestion may in some instances be a *cause* of congestion. To begin with, they typically travel at a slower speed than motorised traffic, potentially impacting negatively on the flow of motorised traffic, although this will be dependent on the level to which users are required to cycle within the motorised traffic stream. In cities with dedicated bicycle lanes and paths, this will be less of an issue. Furthermore, there may be a small negative congestion impact on pedestrians, as docking stations typically occupy sidewalks. Whilst important to identify as a limitation of our proposed evaluation framework, it is felt these negative congestion impacts are likely to be minimal. Mode shift from public transit to PBSS may free up capacity of public transit vehicles, although the magnitude of this benefit is likely to be minimal relative to the size of the public transit system.

CONCLUSIONS

As governments begin to create the conditions necessary to encourage bicycle use, PBSS are continuing to appear and grow in urban areas throughout the world. In order to better understand their impact on the transport system, it is necessary to establish a comprehensive evaluation framework that enables a fair and robust comparison across time for a single program and across programs. Such a framework is currently lacking in the limited body of research investigating PBSS.

This paper has proposed an evaluation framework that directly benchmarks PBSS against their purported benefits, in terms of congestion, greenhouse gas emissions as well as physical activity. This framework will assist private operators and governments in measuring the benefits of PBSS, enabling an improved understanding of how this new form of public transit assists in meeting public policy outcomes.

Using Barcelona as a case study, this paper found that increases in physical activity provide the major benefit of PBSS, with relatively limited congestion and climate change impacts (with carbon price of $20 per tonne). As knowledge on PBSS improve, it will be possible to calculate benefits for a wider selection of variables, include costs, and assess how the program is performing against its stated public policy objectives.

ACKNOWLEDGEMENTS
The authors would like to acknowledge both Russell Meddin of Bike Share Philadelphia and Esther Anaya. Both have been important sources of information. Elliot Fishman would like to thank Meredith Levi for proof reading early versions of this paper.

REFERENCES

1. Dora, C. and F. Racioppi, *Including health in transport policy agendas: the role of health impact assessment analyses and procedures in the European experience*. Bulletin of the World Health Organization, 2003. **81**(6): p. 399-403.
2. Dora, C. and M.A. Phillips, *Transport, environment, and health*, 2000, World Health Organization Regional Office for Europe,: Copenhagen.
3. Pucher, J., J. Dill, and S. Handy, *Infrastructure, programs, and policies to increase bicycling: an international review*. Preventive Medicine, 2010. **50 Suppl 1**(S106): p. 25.
4. Meddin, R. *The Bike-sharing World: First Week of June 2011*. 2011 [cited 2011 Acce13.06.11ss Date]; Available from: http://bike-sharing.blogspot.com/.
5. DeMaio, P., *Bike-sharing: History, impacts, models of provision, & future*. Journal of Public Transportation, 2009. **12**(4): p. 41 - 56.
6. Shaheen, S., S. Guzman, and H. Zhang, *Bikesharing in Europe, the Americas, and Asia*. Transportation Research Record: Journal of the Transportation Research Board, 2010. **2143**(-1): p. 159-167.
7. Bauman, A.E., C. Rissel, J. Garrard, I. Ker, R. Speidel, and E. Fishman, *Cycling: Getting Australia Moving: Barriers, facilitators and interventions to get more Australians physically active through cycling*, 2008, Cycling Promotion Fund.
8. Capital Bike Share. *About us*. 2011 Acce21.07.11ss Date]; Available from: http://www.capitalbikeshare.com/about.
9. Yang, T., P. Haixiao, and S. Qing. *Bike-sharing Systems in Beijing, Shanghai and Hangzhou and Their Impact on Travel Behaviour*. in *Transportation Research Board Annual Meeting 2011*. 2010.
10. Murphy, H., *Dublin Bikes: An Investigation in the Context of Multimodal Transport*, 2010, Dublin Institute of Technology: Dublin. p. 16.
11. Nice Ride Minnesota. *Nice Ride Minnesota Survey November 2010*. 2010 Acce20.06.11ss Date]; Available from: http://appv3.sgizmo.com/reportsview/?key=102593-416326-6d13ea0276ea0822c9f59f4411b6c779.
12. Buttner, J., H. Mlasowsky, T. Birkholz, D. Groper, A.C. Fernandez, G. Emberger, T. Petersen, M. Robert, S.S. Vila, P. Reth, H. Blumel, C.R. Rodriguez, E.P. Pineda, A.B. Piotrowicz, R. Ejsmont, P. Kuropatwinski, M. Kowalewska, F. Vecchiotti, H. Reiterer, S. Robert, J. Gagneur, O. Richard, M. Jean, S. Basterfield, C. Williamson, C. Snead, N. Giles, E. Georgiou, J. Galatik, R. Pliskova, J. Martinek, M. Menichetti, and M. Banfi, *Optimising Bike Sharing in European Cities: A Handbook*, 2011, Intelligent Energy Europe program (IEE).
13. Fuller, D., L. Gauvin, Y. Kestens, M. Daniel, M. Fournier, P. Morency, and L. Drouin, *Use of a New Public Bicycle Share Program in Montreal, Canada*. American Journal of Preventive Medicine, 2011. **41**(1): p. 80-83.
14. Pucher, J. and R. Buehler. *Analysis of Bicycling Trends and Policies in Large North American Cities: Lessons for New York*. 2011 April 2011 Date]; Available from: http://www.utrc2.org/research/assets/176/Analysis-Bike-Final1.pdf.
15. Pucher, J., S. Greaves, and J. Garrard, *Cycling down under: a comparative analysis of bicycling trends and policies in Sydney and Melbourne*. Journal of Transport Geography, 2010. **19**(2): p. 332-345.
16. Fishman, E., I. Ker, J. Garrard, and T. Litman, *Cost and health benefit of active transport in Queensland*, 2011, Produced for Queensland Government: Brisbane.
17. Ker, I., T. Litman, E. Fishman, and J. Garrard, *Cost and health benefit of active transport in Queensland: Evaluation Framework and Values*, 2011, Queensland Health: Brisbane.
18. Shaheen, S., H. Zhang, E. Martin, and S. Guzman, *Hangzhou public bicycle: Understanding early adoption and behavioural response to bike sharing in Hangzhou, China*, in *TRB Annual Meeting*2011: Washington D.C.
19. Pucher, J. and R. Buehler, *Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany*. TRANSPORT REVIEWS, 2008. **28**(4): p. 495-528.

20. Transport for London, *Travel in London Report 3*, 2010, Transport for London: London.
21. Basford, L., S. Reid, T. Lester, J. Thomson, and A. Tolmie, *Drivers' perceptions of cyclists*, 2002, TRL Limited, for the UK Department for Transport.
22. Anaya, E., *Bicycle share research*, 2011: Barcelona.
23. Anaya, E. and M. Bea, *Cost-benefit evaluation of Bicing*, in *ECOMM Conference*2009: San Sebastian/Donostia, Spain.
24. City of Barcelona *The City Council extends Bicing services* 2007.
25. City of Barcelona, *Bicing Press Release*, 2011, City of Barcelona: Barcelona.
26. Jensen, P., J.B. Rouquier, N. Ovtracht, and C. Robardet, *Characterizing the speed and paths of shared bicycle use in Lyon*. TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT, 2010. **15**(8): p. 522-524.
27. Lewis, T., *Has London's cycle hire scheme been a capital idea?*, in *Guardian* 2011, Guardian: London.
28. Brown, A.L. and M. Burke, *Distances People Walk for Transport*. Road & Transport Research: A Journal of Australian and New Zealand Research and Practice, 2007. **16**(3): p. 16-29.