Journal of Transport & Health xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Bicycle-sharing system socio-spatial inequalities in Brazil

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1. Introduction

Bicycle use can contribute to curbing high worldwide levels of physical inactivity, which is responsible for 6% to 10% of the burden of non-communicable diseases, such as Type 2 diabetes, coronary heart disease, and breast and colon cancers (Lee et al., 2012). The benefits also seem to outweigh the risks (i.e. exposure to air pollution (de Hartog et al., 2010; Tainio et al., 2016; Woodcock et al., 2014)). Such benefits make bicycling a key component in improving population health, reducing environmental hazards (e.g., air and noise pollution), and addressing climate change in urban areas (Handy et al., 2014; Hunter et al., 2017). The promotion of bicycling as part of sustainable transport systems has recently been explicitly stated in the international policy paper "New Urban Agenda" (United Nations, 2017).

Bicycle-sharing systems have been used to promote bicycling as a viable means of transport in cities. After a sharp increase in recent years, almost 1200 cities worldwide have bicycle-sharing systems (Meddin, 2017). In Brazil, bicycle-sharing systems have expanded in the last decade due to public-private partnerships promoted by municipalities (Gauthier et al., 2013). Bicycle-sharing systems can provide valuable data, as detailed information on distance, location, and duration of each of the trips can often be obtained for each user (Romanillos et al., 2016). These datasets collect detailed input on the trips which can be linked to the profile of the users, allowing, for instance, for the evaluation of specific health impact outcomes (Rojas-Rueda et al., 2011; Woodcock et al., 2014), with variables for which private bicycling data are either unavailable or incomplete.

Initial evidence on bicycle-sharing systems from high-income countries shows that they seem to attract a specific profile of users in terms of gender (males), ethnicity (white), and work status (employed) (Woodcock et al., 2014). The pool of bicycle-sharing system users also seems to be younger, richer, and more highly educated than the general population where these systems are located (Fishman et al., 2014; Shaheen et al., 2013).

These demographic discrepancies are often exacerbated by the unequal distribution of the stations and covered areas (Clark and Curl, 2016; Ogilvie and Goodman, 2012; Ricci, 2015). Such spatial distribution has been attributed to economic and political goals that favor central and densely populated areas of the city in the initial implementation to maximize the use of the stations. However, such allocation of resources can lead to unequal access to the system (Gauthier et al., 2013; Goodman and Cheshire, 2014). Examples of economic and political goals ruling the implementation of the systems are: managing tourism (in some cases encouraging access, in others restricting it), advertising deals with private entities (such as banks and private companies that sponsor the systems) (Duarte, 2016), public visibility of the actions, and contribution to the image of the city as sustainable or "green" (Ricci, 2015). Improving the

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https://doi.org/10.1016/j.jth.2017.12.011
Received 2 June 2017; Received in revised form 21 December 2017; Accepted 29 December 2017
2214-1405/

connection of bicycle-sharing systems with other modes of public transportation is often not among the main goals of these systems. A better integration of different modes of transportation provides access to users who need to cover longer distances on their daily commutes and/or live far from bicycle-sharing stations.

In Brazil, despite the proliferation of bicycle-sharing systems in large cities, little information is available on where they are located, as well as the technical and political decisions governing their planning and implementation, and to what extent they can contribute with social and spatial inequalities. We thus assessed whether bicycle-sharing systems located in large Brazilian cities are unequally distributed, and performed a document analysis of the planning and implementation process in one of the study cities to understand to what extent this process may contribute to an unequal social and geographic distribution of these systems.

2. Material and methods

We employed a mixed-methods approach to assess the spatial and social inequalities in Brazilian bicycle-sharing systems (Creswell and Clark, 2011). Data were drawn from a survey with bicycle-sharing systems users across five large Brazilian cities and a document analysis of the largest bicycle-sharing system in Brazil.

2.1. Users' characteristics and social and spatial distribution

Using a cross-sectional design, we included in the study only Brazilian capital cities for which bicycle-sharing system and users' characteristics were available: Porto Alegre, Recife, Salvador, Sao Paulo, and Rio de Janeiro. We obtained information on bicycle-sharing systems' users from intercept surveys conducted by the Brazilian Centre of Analysis and Planning (CEBRAP) between June and December of 2014 (Porto Alegre: June; Recife: July - August; Salvador: September - October; Sao Paulo and Rio de Janeiro: November - December).

Secondly, we gathered information on the location of bicycle-sharing stations using the Bike-Sharing World Map (DeMaio and Meddin, 2017). Information on the bicycle-sharing systems partners, subscription rules, and costs were obtained from each management company website and confirmed by phone in July 2016. The geocoded locations of the systems' stations and the number of slots in each station were available at the bike share schemes websites' source code. The source codes were copied to the software Notepad + + 6.7.9.2 in July 8th, 2016, and the information was extracted for each city using a script implemented in Stata 13.1. The outputs from the script were transferred to a geographic information system software. We created the catchment area for each system using buffers of 500 m around each station, which corresponds to the average distance between pairs of nearest neighbor stations in the study sites (465 m) using ArcGIS Desktop 10.4. We used Euclidean distance to calculate the nearest neighbor distance between bicycle-sharing stations QGIS Geographic Information System (QGIS Development Team, 2017).

2.1.1. Statistical analysis

Firstly, we described the characteristics of bicycle-sharing systems catchment areas in each city and compared this with citywide information available at the 2010 Brazilian Census (IBGE, 2016). We compared citywide information on the size of the population covered by each system's catchment area, percent of the population covered by this same catchment area, mean income of the head of the household, and percent of the population who self-declared to be white in each catchment area. Finally, we divided the information on the mean income of the head of the household in the system catchment area by the same information in the entire city to create an income ratio variable.

Secondly, we described users' characteristics by socioeconomic variables: sex, age (10 – 19, 20 – 29, 30 – 39, 40 – 49, 50 – 59, and ≥ 60 years), educational level (elementary school or less, middle school, high school, and college or more), and monthly household income (≤ 2, 2 – 5, 6 – 10, > 10 minimum wages). As of July 2014, the Brazilian minimum wage was R$ 724.00 or US$ 326.00. We then compared users' characteristics with 2010 Brazilian Census data (IBGE, 2016) for each city. Variables included the percentage of males, age, educational level, and mean household income.

To assess whether there were socioeconomic and spatial inequalities in the access to bicycle-sharing systems, we averaged data on the mean income of the head of the household, estimated the total population, the percentage of white residents, and the area covered by each bicycle-sharing system catchment area. We then compared these characteristics with the same variables for the entire municipality. Data were gathered from the most recent Brazilian Census (2010) (IBGE, 2016).

We conducted a sensitivity analysis using buffers of 1000 m around each station to create alternative catchment areas for each system. We decided to test whether a larger distance, which corresponds to approximately 10 minutes of reasonable walking for transportation distance and time (Watson et al., 2015), would produce different results.

Stata 13.1, ArcGIS 10.4, and QGIS Geographic Information System (QGIS Development Team, 2017) were used to perform the analyses.

2.2. Case study

We then conducted a document analysis for the City of Sao Paulo to highlight the decision-making processes behind the spatial outcomes and locations of the bicycle-sharing systems identified in the quantitative portion of this article and to understand to what extent the planning and implementation of this system may have contributed with an unequal access to the stations. We used a critical case study format, following Ragin and Amoroso's (2010) methods and because of the unbounded interfaces between phenomenon and context in this example (Yin, 2008). We thus attempted to understand the complexities and intricacies of the layering of