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Modelling bicycle availability in bicycle sharing systems: A case study from Montreal

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A R T I C L E I N F O

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A B S T R A C T

This paper contributes to the literature on Bicycle Sharing Systems (BSS) by examining bicycle availability at a station as a direct metric of analysis. The main contribution of the current research effort is to develop a behaviorally quantitative model that accommodates for the influence of temporal, meteorological, bicycle infrastructure, built environment and land-use attributes on bicycle availability. An ordered regression model - panel mixed generalized ordered logit model – for hourly bicycle availability is estimated to accommodate for exogenous variables and station level unobserved factors. The model estimation is undertaken using Montreal BIXI data from the summer of 2012. From the results, we observe that BIXI is used more in the afternoon than in the morning, dense areas tend to be associated with lower availability levels, and interactions of time of day with land use impact availability. The estimated model is validated using a hold-out sample. The results clearly highlight the satisfactory performance of the proposed framework. The model developed can be employed by BSS operators to arrive at hourly system state predictions and used for rebalancing operations. To illustrate its applicability, an availability prediction exercise is also undertaken.

1. Introduction

Bicycle sharing systems (BSS) have been receiving increasing attention in recent years as complementary modes of transportation in urban areas around the world (Parkes, Marsden, Shaheen, & Cohen, 2013). Currently, there are over one million public bicycles worldwide, and over 1100 cities have installed or are planning a BSS (Meddin & DeMaio, 2015). These systems present many advantages, including flexibility, ease of access and use, physical activity and health-related benefits. These systems also address the issue of bicycle theft for users, a common problem for regular cyclists in urban environments (Bachand-Marleau, Lee, & El-Geneidy, 2012; Van Lierop et al., 2015). Additionally, BSS offers a potential solution to the “last mile” problem (Cervero, Caldwell, & Cuellar, 2013; Jäppinen, Toivonen, & Salonen, 2013) and are in tune with current generational trends in transportation. Younger generations are less willing to drive, more concerned about the environment, and more prone to use public transit and shared transportation alternatives (Dutzik & Baxandall, 2013).

The observed bicycle flows (arrivals and departures) in a BSS are in response to individuals’ need to travel. Hence, observed flows are significantly influenced by land use and urban form, meteorological and temporal attributes. For example, several studies (Faghih-Imani & Eluru, 2016a,b, Faghih-Imani, Eluru, El-Geneidy, Rabbat, & Haq, 2014) observed clear commuting trends i.e. in the morning period, bicycles were likely to be picked up from stations farther from the Central Business District (CBD) and dropped off at stations in the CBD. Such asymmetric movements of bicycles in a single direction are likely to create empty stations away from the CBD and full stations around the CBD in the morning hours while the opposite is likely to occur in the P.M. peak hours. This pattern can lead to lack of access to bicycles (in empty stations) or lack of empty slots (in full stations) for customers. In addition to the commuting trend, several spatial and temporal relationships can result in asymmetry across the system (Nair, Miller-Hooks, Hampshire, & Bušić, 2013; Zhao, Wang, & Deng, 2015). Such asymmetric usage is a concern for BSS operators because bicycle availability (or empty slot for returning) is at the *heart* of the BSS user-experience. A lack of available bicycles or lack of available space to drop off a bike after usage discourages individuals from using the system. Hence, it is important for system operators to ensure that a desirable level of bicycle availability (or empty slot availability) is maintained. For a fixed station capacity, determining the number of bicycles at the station will automatically determine the number of

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empty slots. Therefore by examining bicycle availability we automatically observe the availability of empty slots.

To address flow imbalances, in most systems, BSS operators transfer bicycles from full stations to empty stations to ensure bicycle (or slot) accessibility in the system - the process referred to as rebalancing. Moreover, from an environmental perspective, since rebalancing trucks are the only source of air pollution related to BSS systems, it is important to minimize negative environmental externalities. Despite the growth of BSS around the world in recent years and the challenges highlighted above, there are very few studies examining the availability of bicycles or empty slots at a station. To be sure, there have been studies on optimizing rebalancing operations using historical data from a data mining based approach (Kloimüllner, Papazek, Hu, & Raidl, 2014). However, these approaches do not consider any behavioral relationships between BSS demand and factors affecting demand such as socio-demographics, time of day and land use.

In this study, we contribute to the literature on BSS by examining bicycle availability at a station as a direct metric of analysis. With the public availability of trip data on BSS provider websites for various cities (such as Chicago, New York and London), several studies have explored system usage (as arrivals and departures). The approach relates the observed usage (arrivals and departures) at a station to various exogenous factors influencing demand. While system usage is an important measure for BSS operators, it still does not directly study bicycle (or slot) accessibility in the system. The primary reason for lack of analysis of this nature is the lack of station level availability information. The operator provided data does not allow us to generate station level availability because the rebalancing flows - BSS operator undertaken removal or addition - are not reported. The observed availability at the BSS station is a net result of user flows and rebalancing flows. Such information can be obtained through a web crawler based script that records the status of bicycle availability (or slot) in continuous time. In this research effort, we employ a web crawler script based database that directly measures availability to identify potentially full or empty stations.

The current research effort develops a behaviorally quantitative model that accommodates for the influence of temporal, meteorological, bicycle infrastructure, built environment and land-use attributes on bicycle availability. The proposed approach allows system operators to forecast the potential problematic stations (full or empty) based on the quantitative model. Furthering current understanding of the factors affecting bicycle availability will yield insights into the supply-and-demand mechanisms of bikesharing systems, and allow the operators to better optimize their rebalancing procedures and/or plan the system modification (addition or relocation of stations and capacity). In fact, the apriori identification will allow the system operators to plan and schedule rebalancing operations minimizing BSS truck movements while also ensuring improved bicycle (or slot) accessibility in the system. The knowledge of expected problematic stations (full or empty) would also help the BSS operators to formulate innovative programs to reduce the need for rebalancing; for instance, some BSS operators are considering incentive programs for their users to pick up a bike at a full station and drop it off at an empty station (for example see the bike angels program of CitiBike in New York City: http://bikeangels.citibikenyc.com/).

The rest of the paper is organized as follows: Section 2 gives some background on BSS and reviews the current literature on the topic; Section 3 presents the data and models used; Section 4 summarizes the results; Section 5 features a validation exercise; and finally, Section 6 outlines some suggestions for future research and concludes the paper.

2. Study in context

2.1. Literature review

In recent years, several studies have examined bicycle flows and usage levels in various bikesharing systems in Europe and North America. These studies can be segmented into three broad groups. The first group of studies employs actual flow data obtained from the system under consideration to investigate the factors affecting BSS flows. Krykewycz, Puchalsky, Rocks, Bonnette, and Jaskiewicz, (2010) investigated a planned system in Philadelphia, Pennsylvania, using a raster based Geographic Information System (GIS) to identify possible locations for BSS while using data from European cities to forecast expected demand. Several studies assessed how bikesharing ridership levels were affected by socio-demographic attributes and built environment around stations (Buck & Buehler, 2012; Rixey, 2013; Rudloff & Lackner, 2014; Zhao, Deng, & Song, 2014; Wang, Lindsey, Schoner, & Harrison, 2012; Mattson & Godavarthy, 2017). A common limitation of these studies is the lack of detailed temporal resolution. Monthly or annual flow estimations fail to capture short term variation due to shifts in weather, as well as the time of day and weekend variation. Several studies considered fine temporal resolution at an hourly level to examine the influence of meteorological, temporal, land use and built environment attributes on hourly arrival and departure rates (Faghih-Imani & Eluru, 2016a, b, Faghih-Imani et al., 2014; Faghih-Imani, Hampshire, Marla, & Eluru, 2017). Recently, McBain and Caulfield (2017) evaluated estimated travel time differences for ridersharing trips by comparing observed travel times to the expected travel times. The study found that locations with higher walking access to shops are likely to experience larger differences.

The second set of studies elicits user experience perceptions and system level effects of bicycle-sharing systems. Several studies examined the differences between BSS short-term users and annual members (Buck et al., 2013; Faghih-Imani & Eluru, 2015, 2018; Lathia, Ahmed, & Capra, 2012). The convenience of bikeshare systems and the proximity of home to a docking station were found to be the greatest encouragement for individuals to use the system (Bachand-Marleau et al., 2012; Fuller et al., 2011). The relationship between BSS and public transit system was examined in several studies (Bachand-Marleau et al., 2012; Faghih-Imani & Eluru, 2015; González et al., 2015). Fishman, Washington, and Haworth (2014) used survey and trip data from five cities to investigate the extent to which BSS can help replace some of the automobile mode share with bicycle share. The study also examined the influence of rebalancing needs in order to determine the impact of BSS on vehicle-kilometers travelled. Bullock, Brereton, and Bailey (2017) investigated the system costs and benefits associated with BSS. The study found overwhelming evidence of significant economic, time and health benefits from BSS based on their analysis of survey day from Dublin. Godavarthy and Taleqani (2017) examined willingness to use BSS in the cold season.

Finally, the third group of studies, and the most relevant to current research, focus on identifying problematic stations (stations that are full or empty). Nair et al. (2013) examined system characteristics, utilization patterns, public transit interaction, and flow imbalances between stations over time for the Vélib' system in Paris, France. The authors adopted a stochastic optimization framework to generate redistribution plans for the Vélib' system. Fricker and Gast (2014), studied the effect of the randomness of user decisions on the number of problematic stations. Vogel and Mattfeld (2011) and Bouveyron, Côme, and Jacques (2015) developed cluster analysis and found different categories of stations within the bikeshare systems. Another subset of studies focuses on operational issues of BSS such as optimizing bicycle repositioning operations and rebalancing truck routing (Forma, Raviv, & Tzur, 2015; Kloimüllner et al., 2014; Pfrommer, Warrington, Schildbach, & Morari, 2014; Raviv, Tzur, & Forma, 2013; Vogel & Mattfeld, 2011).

2.2. Study contribution

The current research effort makes empirical and methodological contributions. Empirically, the study develops a quantitative model to identify stations that are either full or empty, thus providing the system