Journal of Transport Geography 71 (2018) 84–102

Contents lists available at ScienceDirect

Journal of Transport Geography

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

Examining travel patterns and characteristics in a bikesharing network and implications for data-driven decision supports: Case study in the Washington DC area

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ARTICLE INFO

Keywords:
Bikeshare systems
Urban mobility
Data analytics
Origin-destination (O-D) flows

ABSTRACT

Bikesharing has gradually become an adopted form of mobility in urban area recent years as one sustainable transportation mode to bring us many social, environmental, economic, and health-related benefits and rewards. There is increased research toward better understanding of bikesharing systems (BSS) in urban environments. However, our comprehension remains incomplete on the patterns and characteristics of BSS. In this paper, aiming to help improving sustainability in multimodal transportation through BSS, we perform a systematic data analysis to examine underlying patterns and characteristics of the system dynamics in a bikeshare network and to acquire implications of the patterns and characteristics for decision making. As a case study, we use trip history data from the Capital Bikeshare system in the Washington DC area and some additional data sources. The study covers seven important aspects of bikeshare transportation systems, which are respectively trip demand and flow, operating activities, use and idle times, trip purpose, origin-destination flows, mobility, and safety. For these aspects, by using appropriate statistical methods and geographic techniques, we investigate travel patterns and characteristics of BSS from data to evaluate the qualitative and quantitative impacts of the inputs from key stakeholders on main measures of effectiveness such as trip costs, mobility, safety, quality of service, and operational efficiency, where key stakeholders include road users, system operators, and city. We also disclose some new patterns and characteristics of BSS to advance the knowledge on travel behaviors. Finally, we briefly summarize our findings and discuss the implications of the patterns and characteristics for data-driven decision supports from the relations between BSS and key stakeholders for promoting bikeshare utilization and transforming urban transportation to be more sustainable.

1. Introduction

Nowadays, transportation is predominantly dependent on motor vehicles, which has resulted in a practical problem in urban areas, traffic congestion. In 2014, congestion caused urban Americans to spend a cost of $160 billion on substantial delays and extra fuel consumption (Schrank et al., 2015), besides the detrimental impact on environment from the increased vehicle emissions. To tackle the challenges in maintaining urban sustainability, bicycle use as an emission-free substitute for motor vehicles was encouraged and has become an increasing trend in cities around the world (Fishman et al., 2014a, 2014b). Bicycling can either replace driving for the short-to-medium-distance trips, or provide first- and last-mile connections to other transportation modes to facilitate an intermodal transportation system (DeMaio, 2009; Shaheen et al., 2013; Ma et al., 2015). Use of bicycles is hugely rewarding from social, environmental, economic, and health-related aspects for cities, communities and bike users. Benefits of alleviating congestion and mitigating associated environmental damages accrue from the vehicle miles traveled (VMT) in transportation reduced by bicycling (Hamilton and Wichman, 2018; Wang and Zhou, 2017). Accessibility to neighborhoods is enhanced by bicycling to boost economic opportunities to local businesses (Buehler and Hamre, 2015). Moreover, as an active transportation mode, bicycling not only plays a unique role in supporting recreational trips, but also provides substantial public health advantages (Shaheen et al., 2013; Mueller et al., 2015). In terms of the increased physical activity, bicycling is shown quite effective for reducing potential health risks (Mueller et al., 2015; Fishman, 2016).

In recent years, many cities have improved their cycling infrastructure. The adoption of the bicycling mode in transportation has

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https://doi.org/10.1016/j.jtrangeo.2018.07.010
Received 16 August 2017; Received in revised form 6 July 2018; Accepted 13 July 2018
0966-6923/

experienced significant growth. According to American Community Survey (ACS) 2008–2012 (McKenzie, 2014), commuting by bike had a percentage increase about 61% from 2000, which increased larger than any other commuting mode. More cities around the world have invested substantially in public bicycle programs or bikesharing systems (BSS) (DeMaio, 2009; Shaheen et al., 2013; O'Brien et al., 2014; Fishman, 2016). Incorporated with information technology, BSS allows users to immediately reserve, pickup, and drop-off public bikes in the network of docking stations at an affordable cost of paying some user or membership fee for bike riding services. Compared to private bikes, BSS not only makes users freed from ownership and regular maintenance of bike, but also allows users to bike one way to connect with other transportation modes with more flexibility on intermodal trips. In 2017, over 1000 cities have offered bikeshare programs and over 4.5 million public bicycles have been in use (Meddin and DeMaio, 2017).

As a new form of mobility that gradually emerged, BSS has attracted much interest and attention in research. Analysis of surveys and data (Romanillos et al., 2016) have been performed by the operators and analysts who aim to achieve a better understand on the system states and key factors influencing the user experiences and the effectiveness of BSS, and on the role of BSS in transforming future urban mobility. Various aspects of bikesharing have been studied. O'Brien et al. (2014) classified 38 BSSs based on an analysis of variations in occupancy rate. A few studies provided basic insights concerning the impacts of seasonal weather and temporal trends on bicycling in urban environments (Gebhart and Noland, 2014; El-Assi et al., 2017). Corresponding to bikeshare users, several studies summarized data and surveys on some significant differences of the user behaviors in terms of their demographic characteristics (Zhao et al., 2015; LDA Consulting, 2016; Bhat et al., 2017). Some other research analyzed the difference of the trip attributes to gain some understandings on trip purposes, especially between round and one-way trips (Zhao et al., 2015; Noland et al., 2017) and between casual and member users (Buck et al., 2013; Wergin and Buehler, 2017; Noland et al., 2017) among other factors (Fishman, 2016).

Mobility and safety are two main factors for road users to make their mode choice of transportation and for urban planners and policy makers to improve transportation systems. Concerning the bikeshare mobility, some initial studies have been conducted in literature. As shown in the survey by Moritz (1997), the average speed of bicycle commuting was 14.6 mph. Wergin and Buehler (2017) estimated the average speed using a small sample of 3596 trips with GPS tracking data. Perez et al. (2017) studied the impact of mobility from the viewpoint of accessibility in the bike lane network. As sharing road with vehicles, cyclists are vulnerable users that are more likely to be injured when involved in traffic collisions. According to NHTSA (2017), 818 bicyclists were killed and an additional estimated 45,000 were injured in traffic crashes in USA in 2015. Lowry et al. (2016) classified bike roads in a network in terms of stress levels (Rixey and Prabhakar, 2017). Other studies were performed to understand the crash risk of bikeshare users (Martin et al., 2016; Fishman and Schepers, 2016).

It has been a common interest for researchers and operators to push BBS into demand-responsive operations. A few studies examined BSS usage and traffic patterns at different levels of spatio-temporal aggregation to recognize the impacts of contributing indicators on BSS demand (Fournier et al., 2017; Jestico et al., 2016; Faghih-Imani and Eluru, 2016). Vogel et al. (2011) applied clustering-based data mining to explore activity patterns, which revealed the imbalances in the spatial distribution of bikes in BSS. O'Brien et al. (2014) documented the redistribution problem of bikes in BSS from the variations in load factor. Some studies (de Chardon et al., 2016; Fishman, 2016; Faghih-Imani et al., 2017) proposed bike rebalancing methods (e.g., trucks and corral services of BSS) to help solving the imbalance between demand and supply at bike stations so that to improve the operational efficiency for BSS and to meet the service level agreements (SLA) and guarantee the quality of service (QoS) for users. Finding a more cost-effective way for sustainable operations requires us to harness the spatio-temporal flow patterns of bikesharing.

However, our understanding remains incomplete on the patterns and characteristics of BSS. For example, the impacts from some operational activities of BSS on the patterns and characteristics have not been investigated. Some fundamental questions remain open even on the known patterns and characteristics of BSS, particularly on their implications for the potential decision supports toward sustainable transportation in complex urban environments. As a function of moving people in the spatio-temporal dimensions using shared bikes, BSS outputs the patterns and characteristics according to the integrated inputs combining many critical factors provided by the stakeholders, including infrastructures, policies, operating activities, management agreements, trip information (such as purpose, route, origin, destination) and etc. Incorporating these inputs from key stakeholders into BSS modeling and analysis is essential to understand the patterns and characteristics for the decision making of improving sustainability in multimodal transportation through BSS. Some corresponding unsolved questions include (but are not limited to), for example, how to link these inputs with the patterns and characteristics to better understand their impacts on BSS for decision making? Referring to the inputs from different stakeholders, what do the patterns and characteristics imply on key measures of effectiveness (MoE) and supports to BSS? What roles would the patterns and characteristics from data play for decision making of BSS? Notice that urban transportation is a complex system, and in contrast, our available data and computational resources are rather limited. It is challenging to promptly provide a fully automated data-driven decision making that is realistic and efficient for BSS, although some successful efforts on data-driven decision supports (DDDS) have been put in the recent non-BSS transportation research (Cesme et al., 2017; Yi and Shirk, 2018; Zhou et al., 2017) to prove the value of DDDS in offering intelligence and performance monitoring for decision making (Power, 2008). To unleash the potentials of BSS in fostering sustainable multimodal urban transportation, we need take initial steps to bridge the gap between the current comprehension on the patterns and characteristics of BSS and the needs from the BSS modeling and applications for practical and effective data-driven decision supports.

In this paper, we perform a comprehensive data analysis to examine the underlying patterns and characteristics of BSS embedded in a complex urban environment. Aiming to help improving sustainability in multimodal transportation through BSS, we also investigate the implications of the patterns and characteristics for data-driven decision supports (DDDS). We choose the trip history data from Capital Bikeshare (2017b) as our main data source of case study. The Capital Bikeshare (CaBi) system is a public-private venture operating > 3500 bicycles to casual and member users at over 400 stations in the Washington metropolitan area (LDA Consulting, 2016). The data contains 14 million anonymous individual bike trips between 2012 and 2016. Beyond CaBi, we also extract related information from auxiliary data sources, including the Google Maps application program interfaces (APIs) from Google (2017), LEHD Origin-Destination Employment Statistics (LODES) from USCB (2017), and the crash data from Open Data DC in OCTO, DC (2017). We use data visualization, data fusion, data analysis, and statistical analysis to systematically investigate BSS scheme and examine travel patterns and characteristics on seven important aspects, which are respectively trip demand and flow, operating activities, use and idle times, trip purpose, origin-destination (O-D) flows, mobility, and safety. For each aspect, we explore the results to discuss qualitative and quantitative impacts of the inputs from various stakeholders of BSS on key measures of effectiveness (MoE) such as trip costs, mobility, safety, quality of service, and operational efficiency. We are also interested in revealing new patterns and characteristics of BSS to expand our knowledge on travel behaviors. Finally, we briefly discuss the implications of the patterns and characteristics and some critical roles for data-driven decision supports from the relations between BSS and key stakeholders to show and summarize the values of our