



Understanding bikeshare mode as a feeder to metro by isolating metro-bikeshare transfers from smart card data

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ABSTRACT

Though metro systems are established in many Chinese cities including Nanjing, they have yet covered every corner of a city. Bikeshare as a feeder mode to metro helps solve the last mile problem. Thus, it is necessary to monitor and analyze metro-bikeshare transfer characteristics. The primary objective of this study is to derive a reproducible methodology that isolates bicycle-metro transfer trips using smart card data. Two recognition rules proposed are a maximum transfer time of 10 min and a maximum transfer distance of 300 m. To explore the general characteristics of metro-bikeshare transfer trips, transfer stations served at less than 30 transfer trips during three consecutive weeks were eliminated to ensure that a non-typical transfer pattern would not distort the results. The results show that more than 89% passengers recognized have less than 6 transfers in 3 weeks, indicating that most users integrate bikeshare with metro impromptu. Two transfer peaks on workdays are during 7:00–9:00 and 17:00–19:00, especially in suburban areas, while at weekends, transfers show quite even during 8:00–19:00. As to “Return-Enter” and “Exit-Lease” transfer modes, the “time difference” phenomenon does exist, which means that the transfer peak of “Return-Enter” mode always happens one hour earlier than that of “Exit-Lease”. Furthermore, the demographic differences in metro-bikeshare usage pattern are revealed. Finally, policy implications are involved to improve the performance of metro-bikeshare integration for all kinds of people without creating inequity.

1. Introduction

Previous studies have indicated that a synergy of metro with bicycles gives the system unique speed and accessibility, making it potentially competitive with unsustainable individual motorized modes, especially during peak hour periods (Kager et al., 2016; Tian et al., 2009). Using the bicycle as a transfer mode for metro can save travel time (Jäppinen et al., 2013; Pan et al., 2010); increase the share of sustainable means of transport (Martens, 2007); improve cyclists' mobility by overcoming topographical, weather, safety, and infrastructure barriers (Hooper, 1995; Wang and Liu, 2013); extend the catchment areas of metro stops (Fishman et al., 2014; Kager et al., 2016); provide personal health benefits (Pucher et al., 2010); offer environmental benefits (Cervero, 2001); shrink surface car parking lots and promote social justice for transit users who do not own cars (Cervero et al., 2013).

Modern bikeshare schemes have the potential to overcome some

major shortcomings of integrating private bicycles and metro. First, metro-bikeshare systems enable citizens to use bicycles on a flexible “as needed” basis, potentially making transit and biking simpler options for more frequent use (Demaio and Gifford, 2004; Shaheen et al., 2010). Second, cities with high levels of transit usage and cycling face onboard capacity constraints. Bikeshare systems at metro stations could help alleviate the crowding of transit systems related to onboard bicycles (Cervero and Gorham, 1995; Flamm, 2013; Griffin and Sener, 2016). Third, encouraging bicycle use for egress trips is more difficult, as some public transportation policies do not allow bicycles to be brought onto transit vehicles at certain times of day. In these situations, a case could be made for bikeshare to make it simpler for commuters on the last leg of their public transport journeys (Bachand-Marleau et al., 2011; Demaio and Gifford, 2004; Fishman, 2016). Fourth, as bicycle vandalism and theft often occur around transit stations, bikeshare systems help encourage rail commuters who worry about or have experienced bicycle thefts to apply bikeshare-metro integration (Ji et al., 2016; Pan

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et al., 2010).

In China, a marriage between the bikeshare and the metro could greatly benefit transportation development. First, China has been going through a phase of unprecedented expansion in both bikeshare programs and urban metro systems. Second, extending metro systems into suburban and exurban areas often requires higher costs, while an effective multimodal transfer system would help expand the service to cover more locations and cut travel time (Fan et al., 2016; Pan et al., 2010). Instead of walking for a long time, cycling is a good solution to travel to locations beyond the reach of the metro (Cheng and Liu, 2012; Li et al., 2014). Third, bikeshare-metro integration is especially important in Chinese cities where public transit systems are notoriously crowded while bicycles are banned on buses and metro. Additionally, as the socio-demographic characteristics of cyclists in China are similar to those in communities of the general population (Yang and Zacharias, 2015), many citizens may be tempted to shift their trip modes into metro-bikeshare integration mode. Finally, a number of Chinese cities have successfully combined bikeshare programs in the city and allowed smart cards to be used interchangeably between bikeshare and public transit, which will further improve the service of bikeshare-metro integration systems (Ji et al., 2016).

Despite the rising interest in metro-bikeshare and the number of countries that are developing general measures to facilitate metro-bikeshare, knowledge on the following topics is scarce:

- How to isolate valid transfer records that belong to one person using smart card data;
- Whether the nuances of metro-bikeshare usage exist substantially across demographic groups and locations in the context of Chinese cities; and
- How to produce effective measures to attract more people to the metro-bikeshare system from a social equity perspective.

In response to these questions, this study proposes a novel data-fusion method to isolate valid metro-bikeshare transfer trips by matching the metro and bikeshare smart cards of one passenger; and then the metro-bikeshare transfer patterns are explored from multiple angles. Finally, several suggestions from a social equity perspective have been put forward to improve the combination between metro and bikeshare. The rest of the paper is organized as follows. The next section reviews existing research on metro-bikeshare usage patterns and measures to promote metro-bikeshare integration. Subsequently, the paper introduces the study area, the smart card data source, and the methodology to recognize transfer trips from the smart card database. Afterwards, the data analysis results are presented via a series of visualizations. The conclusions and suggestions for future research are summarized in the last section of the paper.

2. Literature review

There is extensive literature on combinations of cycling and transit, and the number is growing rapidly. Multiple articles have summarized a range of bicycle-transit integration topics, including the travel characteristics of bicycle-transit integrated trips (Cheng and Liu, 2012; Martens, 2004; Pan et al., 2010; Rose et al., 2016; Wang and Liu, 2013), the accessibility of bicycle-transit (Flamm and Rivasplata, 2014; Hochmair, 2014; Iacono et al., 2008; Keijer and Rietveld, 2000; Rietveld, 2000), bicycle parking issues at railway stations (Arbis et al., 2014; Mead et al., 2016; Molin and Maat, 2015), the bicycle-transit demand forecast (Caulfield et al., 2012; Hendricks and Outwater, 1998; Jingxu et al., 2013), and the determinants of general bicycle-transit integration (Anable, 2005; Mead et al., 2016; Pan et al., 2010; Rose et al., 2016; Taylor and Mahmassani, 1997; Zhao and Li, 2017). However, the emphasis of this literature review is on the integration of the bikeshare with the metro. Such a review is challenging as empirical evidence on how to improve the integration between bikeshare and

metro has been fragmentary. The limited literature on this topic focused on metro-bikeshare usage and on measures to improve metro-bikeshare integration.

2.1. Metro-bikeshare usage pattern

To provide a more in-depth analysis of metro-bikeshare integration behavior, both Ji et al. (2016) and Yang et al. (2016) focused on metro-bikeshare integrators and used Nanjing as a case study, conducting questionnaire surveys. Using a nested logit model, Ji et al. (2016) found that metro commuters who are female, old-aged, and low-income are less likely to use bikeshare for metro transfer. While those who have experienced bicycle theft and those making education- or work-related trips are more likely to do so. Yang et al. (2016) found that metro-bikeshare is a more comfortable, simple, and efficient mode for many suburban commuters. Many commuters who drive medium to long distances daily strongly favor the metro-bikeshare as an alternative commute mode. In addition, male motorists and commuters who have unpleasant experiences are more likely to be attracted to the corresponding features of the metro-bikeshare system. Compared to the sample size of the abovementioned studies, Bachand-Marleau et al. (2011) and Chen et al. (2012) had generally large survey samples of 1432 and 1784, respectively. However, private bicycle users were included in the surveys. Bachand-Marleau et al. (2011) found that over one-third of survey respondents reported having used bikeshare. Bikeshare users, especially those with a yearly membership, were most likely to integrate bikeshare and transit. Chen et al. (2012) found that more than half of the metro users have a preference for bicycle transfer services, and those travelers are making trips for non-time-sensitive purposes, such as shopping and visiting friends, and to a lesser extent, going to work and school. The reason for this result may be that the sample size is mixed with private bicycle users. Some scholars also took advantage of historical bikeshare data and metro-station-built environment data. Specifically, Erdoğan et al. (2015) explored the bikeshare usage around metro stations and the interactions between bikeshare programs and metro ridership; Hong et al. (2016) measured public transport accessibility in the presence of a bikeshare system, and Griffin and Sener (2016) designed a framework for integrated bikeshare and metro planning.

None of the aforementioned studies used smart card data combined with both metro and bikeshare systems and thus have a series of problems, such as inadequate sample size, restricted study generalizability, and failure to analyze the travel behavior of metro-bikeshare from a dynamic variation of the spatio-temporal pattern perspective. Specifically, most related studies, however, fell into an either-or situation. Studies using survey data are very costly and difficult to implement at a multiday level due to low response rate and accuracy; it is also unclear how the integration usage changes across space and over time. In addition, the nuances of socio-demographic diversity of metro-bikeshare remain murky. When the focus is on historical bikeshare data and metro station data, only macro relationships can be explored, and the real transfer trips cannot be determined from a personal perspective.

2.2. Measures to promote metro-bikeshare

Empirically, some good suggestions are put forward regarding improving metro-bikeshare integration. This literature review focuses on “hard” policies, such as planning bikeshare stations and facility construction, as well as “soft” policies, such as humanized services and incentives.

2.3. “Hard” policies

Griffin and Sener (2016)'s team suggested a planning framework for developing partnerships among bikeshare companies, transportation

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