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Understanding the impacts of a public transit disruption on bicycle sharing mobility patterns: A case of Tube strike in London

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ABSTRACT

The interdependencies between bicycle sharing and public transportation systems are not yet fully understood. This paper aims to measure and characterize the impacts of a public transportation disruption on bicycle sharing mobility patterns in London using data from more than 1 million bicycle trips from July 2015. The paper provides a comparative analysis of bicycle sharing spatial mobility patterns before, during, and after a disruption in public transportation system. We also apply a complex network-theoretic approach to uncover the impact of the disruption on the connectivity of the bicycle sharing usage network. We found that the disruption in public transportation in London increased the total number of bicycle sharing trips by 85% from an average 38,886 to 72,503 trips per day. The duration of trips also increased by 88% from an average 23 to 43 min. The disruption also had a considerable impact on the structure and properties of the bicycle sharing mobility network. The connectivity of the network of bicycle sharing trips increased by 88% from 0.102 to 0.187. We found that many of the observed changes are heterogeneously distributed over space suggesting that the impact of the disruption was not uniform across the network. However, the structure of communities in the bicycle sharing mobility network remained roughly invariant from day to day. The applied geo-statistical approach complemented with the complex network-driven methodology provides a better understanding of the interdependencies between the bicycle sharing and public transportation systems in London.

1. Introduction

Bicycle sharing systems are increasingly viewed as a means of public transit to be integrated into the urban transportation network (Replogle, 1984; Doolittle and Porter, 1994; Pucher and Buehler, 2009; Shaheen et al., 2010). Such integration can improve the overall efficiency of the urban transportation system, but they may also increase the system vulnerability (Berdica, 2002). Mattsson and Jenelius (2015) categorize causes of disruptions in transportation infrastructure into two major types of internal and external. Internal causes may be due to unintentional human (staff or users) or technical errors/failures, or intentional events such as strikes or labor market conflicts. External causes mostly pertain to natural disasters and inclement weather conditions. There are a number of studies in the literature that aim to capture the impacts of disruptive events on performance of public transportation (Latora and Marchiori, 2005; Angeloudis and Fisk, 2006; Berche et al., 2012). Mattsson and Jenelius (2015) argue that disruptions in urban areas that target one mode of transportation may result in congestion or overuse of other modes. For instance, they suggest that when there is a public transit strike, private cars, walking and biking may constitute commuters' remaining choices and thus, would be directly influenced. Nonetheless, there are very few studies in the literature investigating the impact of a public transportation disruption on bicycle sharing use (Fuller et al., 2012). Even though we are aware of the existence of interconnection between these two mobility systems, we are far from fully understanding and quantifying their interdependencies. This paper aims to better understand, measure, and characterize these interdependencies by examining the impact of a Tube strike on July 9th, 2015 on bicycle sharing system usage and mobility patterns in London.

First, we present a spatial-temporal analysis of bicycle sharing trip counts and durations for a better understanding of the impact of the disruption. We then, explore the bicycle sharing patterns as a weighted directed graph, providing a comparative network theoretic analysis of

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bicycle sharing mobility network before, during, and after the disruption in the public transportation system. The combined geo-statistical approach and the complex network methodology (Saberi et al., 2016) used here provide a unique view of the interdependencies between the bicycle sharing and public transportation systems in London.

The remainder of the paper is organized as following. Section 2 provides a comprehensive literature review on public bicycle sharing systems with a focus on integration with public transportation systems. Section 3 describes the data used in the analysis. Section 4 presents the results of a spatial-temporal analysis of bicycle sharing system in London. Section 5 presents a complex network-theoretic approach as a supplementary methodology in understanding the mobility characteristics of the bicycle sharing system. Finally, in Section 6 we conclude the paper and provide a series of insights on the impact of the studied disruption on the bicycle sharing usage in London followed by a number of policy implications.

2. Literature review

Public bicycle sharing systems have been around for over half a century. The last decade or so, however, has brought about drastic growth of these programs (Shaheen et al., 2010; Meddin and DeMaio, 2012). Only a handful of cities had a public bicycle sharing system in the late 1990s. This number grew to over 800 cities in 2014 (Shaheen et al., 2010; Meddin and DeMaio, 2012). Fishman (2015) suggests that growing public and government awareness of the negative impacts of car use coupled with increasingly affordable payment and advancement of tracking technologies, account for such substantial expansion of bicycle sharing systems. Shaheen et al. (2010) list a wide range of potential benefits of implementing such systems including flexible mobility, reduction in emissions, increase in physical activity, reduced fuel use, and support for multi-modal transportation systems.

Integrating bicycle sharing into other transportation systems (e.g. public transit) is one of the goals for these systems (Martens, 2007; Krizek and Stonebraker, 2010; Krizek and Stonebraker, 2011; Marleau et al., 2011; Wang and Liu, 2013; Clifton and Singleton, 2014; Tsenkova and Mahalek, 2014; Griffin and Sener, 2016). In a review study, Fishman et al. (2013) investigated the literature on bicycle sharing to identify users' motivations as well as what can discourage them. They realized the most important factor in choosing bicycle sharing was convenience; bicycle share users consistently reported that they use bicycle share because it provided a time and cost competitive alternative to existing modes. Another very important finding was that many bicycle share programs had not attracted many users from motorized transportation, and the users switched from other sustainable modes. Thus, reducing car use that is a primary goal for these programs is yet to be fulfilled. In another study, Fishman et al. (2014a) examined bicycle share programs in five cities across the world to uncover how much bicycle share programs reduce car use. Authors found that reduction in vehicles' traveled distance as a result of bicycle sharing was two times greater than the distance bicycle re-balancing vehicles traversed, except in London. Fishman et al. (2014a) also suggested that bicycle share ridership can escalate with appropriate policy changes, improved accessibility of stations, and improving riders safety. More recently, Chen and Lu (2015) explored the influence of subjective norms on bicycle share use in Taipei, Taiwan. They realized that perception of the level of physical effort bicycle sharing requires has no direct influence on choosing it, but indirectly affects it through users' feelings or attitude. Chen and Lu (2015) recommended that policy makers can exploit these insights and raise users' opinions about bicycle share.

The recent advances in information and communication technologies have made it possible to collect large amount of time- and location-specific data of bicycle sharing use in many cities across the globe which enables the study of bicycle sharing travel behavior and mobility patterns (Beecham and Wood, 2014). The two types of data commonly used for analyzing bicycle sharing systems are information about availability of bicycles at each station and bicycle flow information between station pairs. Due to the less availability and complexity of flow information, only a small number of studies have explored such rich data focusing more on the operational aspect of bicycle sharing systems such as characterization of speed, path choices, supply-demand balancing, and impact of weather conditions (Corcoran et al., 2014; Zhou, 2015; Jensen et al., 2010; Nair et al., 2013; Gebhart and Noland, 2014).

Froehlich et al. (2009) explored station usage logs from Barcelona's bicycle share program to understand spatial-temporal dynamics of bicycle sharing. They also developed simple models to predict station usage, with emphasis on bicycle availability at a certain time into the future. Vogel et al. (2011) analyzed data from Vienna's bicycle share program to support their hypothesis that bicycle activity depends on station location and is also time-oriented. In another study, Padgham (2012) analyzed London bicycle sharing data to explore spatial variations of journey distances, directions and counts. He describes these patterns as directed relationships, i.e. moving towards or away from, or as diffusive relationships, i.e. happening around, with locations of significance. Lathia et al. (2012) investigated the London's bicycle share station data to examine influence of a user-access policy change. Etienne and Latifa (2014) introduced a model-based clustering technique to analyze data generated by bicycle share programs. Faghih-Imani and Eluru (2015) provided models to conjecture bicycle trip destination choice on the basis of variables including distance, land use, built environment, and access to public transportation infrastructure. Wang et al. (2015) explored data from Minneapolis-St. Paul bicycle sharing system and observed a correlation between station activities, i.e. inbound and outbound bicycle trips, and presence of adjacent businesses and jobs.

Despite the growing number of studies on bicycle sharing system (Lu, 2016; O'brien et al., 2014; Faghih-Imani et al., 2014; Fishman et al., 2014b; Martin and Shaheen, 2014; Parkes et al., 2013), there are very few studies exploring the impact of a disruption in the urban transportation system on bicycle sharing demand patterns. Fuller et al. (2012) studied the effects of two London Tube strikes on bicycle sharing demand. They, however, applied a time-series approach and developed a segmented regression model. They found that disruption in the Tube service resulted in statistically significant increase in total number of bicycle trips per day, while the observed increase in mean trip duration was insignificant. In another study, Austwick et al. (2013) applied a complex network motivated approach, as well as multiple descriptive statistics and analytic tools of visualization, to study bicycle sharing systems in five different cities. They highlighted that network methods to understand spatial systems has been relatively under-utilized, and was used to discern local features and communities. They found similar aggregate characteristics, such as similar journey distances, across the systems they studied. Table 1 provides a summary of issues, methods, data used and contributions of a selected number of studies on bicycle sharing since 2013.

3. Data description

The London bicycle sharing system came into service in 2010 with 5000 bicycles and 315 stations distributed across the City of London area and parts of its boroughs. After five years of development, the system now has over 13,351 bicycles and 762 docking stations. Bicycles can be rented at any time if accessible. The use for less than 30 min will be free of charge in favor of short trips. For longer hires, each extra 30 min would cost £2. The largest bicycle sharing systems worldwide are located in China. The London bicycle sharing system is the second largest public bicycle sharing system in Europe after the Velib system in Paris. The coverage of the London bicycle sharing system is, however, limited to the more central areas. Many of the bicycle stations are located fairly close to the public transit routes. However, there is still a