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Understanding bike share cyclist route choice using GPS data: Comparing dominant routes and shortest paths

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ABSTRACT

This paper investigates cyclist route choices using global positioning system (GPS) data collected from 750 bicycles in Hamilton, Ontario's bike share system – SoBi (Social Bicycles) Hamilton. A dataset containing 161,426 GPS trajectories describing observed routes of cyclists using SoBi bikes over a 12-month period (April 1, 2015 to March 31, 2016) is used for analysis. This study groups trips by origin-destination hub pairs and uses a GIS (geographic information system)-based map-matching algorithm to generate routes along with attributes such as length, number of intersections, number of turns, and unique road segments. Unique routes and their use frequencies are extracted from all the hub-to-hub trips using a GIS-based link signature extraction tool developed for this research. The most popular routes between hubs taken by cyclists are then identified as dominant routes and their attributes are compared to those of corresponding shortest path routes derived by minimizing distance traveled. The comparison finds significant differences in multiple attributes, and demonstrates that dominant routes are significantly longer than their shortest distance counterparts, suggesting that cyclists are willing to detour for routes characterized by positive features such as bicycle facilities and low traffic volumes. Detouring does, however, come at a cost – increases in number of turns and number of intersections. This research not only enhances our understanding of cyclist route preferences within a bike share system, it also presents a GIS-based approach for identifying potential locations for future bike facilities based on such preferences.

1. Introduction

Active travel, any form of human-powered transportation like bicycling and walking, benefits not only physical fitness (Merom et al., 2010; Sahlqvist et al., 2012; Saunders et al., 2013), but also social and cognitive development (Badland and Oliver, 2012). For this reason, policy makers and urban planners continue to seek ways of increasing the use of active commute modes (Sallis et al., 2006; St-Louis et al., 2014). It has been suggested that cycling is more likely to replace motorized travel modes than walking given its faster speed and capability of covering longer distances, though most of the focus recently has been placed on walking (Dill, 2009). Cycling can benefit not only the environment by reducing carbon emissions (Woodcock et al., 2009), but also health by reducing obesity, chronic diseases, and weight gain (Andersen et al., 2000; Oja et al., 2011; Pucher et al., 2010). Bike share programs (BSP), providing bikes that can be picked up and dropped off at self-serve docking stations, have grown rapidly in past years; for example, the number of participating cities has increased from 13 in 2004 to 855 in 2014 (Fishman, 2015). Hamilton, Ontario is one such city operating a BSP commonly referred to as SoBi (Social Bicycles) Hamilton, which, at the time of its official launch in March 2015, had 750 GPS (global positioning system)-equipped bicycles located at over 100 hubs. The GPS feature means that cyclist routes can be tracked in real-time, providing an opportunity for route choice analysis.

In general terms, route choice analysis is necessary to appraise perceptions of route attributes, to forecast future traffic conditions on road networks, to simulate travel behavior under hypothetical scenarios, and to look at response and adaptation to message sources (Prato, 2009). Government policy makers, researchers, and professionals can understand individual travel preferences by analyzing the route choice decision-making process in an effort to identify related determinants in terms of route attributes and the demographic characteristics of travelers. In the context of walking and cycling, they can develop policies and build facilities for encouraging greater use of such active travel modes. For example, studies of cyclist routes can help to identify what types of regulations and cycling infrastructure programs are useful in promoting the use of the bicycle for utilitarian trips in order to reduce automobile usage (Aultman-Hall et al., 1997; Su et al., 2010).

Most route choice studies create alternative routes using choice set

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generation methods. However, this research generates routes for all the trips between SoBi hubs from GPS data using a GIS (geographic information system)-based map-matching algorithm (Dalumpines and Scott, 2011, 2018), and extracts unique routes from those duplicate hub-to-hub trips using a link signature extraction tool developed for this study. As a result, for a hub pair, it is possible to create choice sets of observed and alternative routes from actual routes taken by SoBi users instead of creating alternative routes using various techniques. Unlike most previous research based on individuals, this study generates choice sets on the basis of hub pairs to control origins and destinations for routes and investigates characteristics of these hub-to-hub routes within the BSP. Between a hub pair, the unique route with a maximum number of trips on it is regarded as the dominant route. As such, this study presents a new and essential attempt to explore the spatial distribution of dominant routes, which visually provides planners with road segments suitable for developing bicycle facilities. Given the usage frequencies of unique routes, extraction of hub-to-hub dominant routes can help determine cyclists' preferences. In this study, this is achieved by comparing attributes between dominant routes and shortest path routes (derived by minimizing travel distance), thereby identifying potential factors affecting cyclist behavior. Although SoBi Hamilton provides a real-time app for its users to show the number of bicycles and docks available at each hub, the app is not able to recommend optimal cycling routes. In this case, the dominant route between a hub pair could be considered the optimal route rather than a shortest path because it is frequently chosen by multiple SoBi users. Finally, this study complements other recent studies, such as those by Khatri et al. (2016) and Wergin and Buehler (2017), by also demonstrating the usefulness of using bike share data for understanding route choice decisions given that bicycles from recent BSPs are usually equipped with GPS devices.

The remainder of this paper is organized as follows. Section 2 reviews methods to collect data for route choice analysis and discusses variables, including route attributes and cyclist characteristics, affecting cyclist route choice behavior. Section 3 describes briefly the study area and sources of both the cycling network and GPS dataset. Section 4 discusses the generation of route choice sets using the GIS-based map-matching algorithm and link signature tool, and the methods of analysis involving the normalized Gini coefficient and paired *t*-test. Results from the analysis are found in Section 5. Section 6 summarizes major findings, limitations, and future implications of this research.

2. Background

2.1. Data collection methods

Most previous bicycle route choice studies used stated preference (SP) surveys or revealed preference (RP) surveys as the data collection method (Aultman-Hall et al., 1997; Guttenplan and Patten, 1995; Howard and Burns, 2001; Hunt and Abraham, 2007; Tilahun et al., 2007). Respondents for SP surveys make a choice among different facilities or different route options, forcing them to trade off some positive features (Broach et al., 2012). According to Abraham et al. (2002), SP surveys can collect a large sample of data easily and cheaply, and avoid inter-correlations among attributes, but the ability of respondents to mentally convert their usual routes and preferred facilities to match the created choice set in the survey may lead to missing some important features for route choices. On the contrary, RP surveys gather information based on actual route choices made by participants, so the collected data can reveal preferences in a real choice environment. However, the tedious and time-consuming collection process limits the sample size, and the capability of participants to precisely recall routes influences the match between revealed routes and actual route networks (Stinson and Bhat, 2003). In order to accurately recall routes that participants choose, GPS devices that can automatically record traces have been used for data collection in many more recent route choice studies including Broach et al. (2012), Hood et al. (2011), Khatri et al. (2016), Menghini et al. (2010), and Wergin and Buehler (2017). The drawbacks to using GPS data for research include the high cost of equipping GPS devices and the transformation of points recorded by devices into actual traces that users take.

2.2. Potential determinants of cyclist route choice behavior

Some work has regarded travel time or distance as the most important factor influencing the route choices of cyclists for commuting purposes (Aultman-Hall et al., 1997; Sener et al., 2009; Stinson and Bhat, 2003). However, Tilahun et al. (2007) discovered bicycle route preferences of trading off travel time for particular facilities, such as designated bike lanes, trails off street, and parking on the street side. Similarly, Winters et al. (2010b) found that utilitarian bicycle trips are 360 m longer than shortest path routes in Metro Vancouver because cyclists are willing to detour slightly to ride on routes with more bicycle facilities.

Almost all the earlier studies explore the influence of bicycle facility type on commuter cyclist route choice. Broach et al. (2012) illustrated that off-street/separated bike paths that definitely have no motorized traffic are preferred, followed by bike boulevards that are neighborhood streets with traffic calming features. Simultaneously, on-street bike lanes can more or less mitigate the negative influence of traffic nearby, so they are more attractive than a heavy traffic street without a bike lane, but not preferred compared to a street with low traffic volume (Broach et al., 2012). Winters and Teschke (2010) found the order of bicycle route preferences: off-street paths, physically separated routes adjacent to main streets, neighborhood routes, rural roads, and routes on major roads. However, these findings are opposite to some studies that have found that bike lanes on streets are more attractive than separated bike paths followed by routes without bicycle facilities (Hood et al., 2011; Sener et al., 2009; Stinson and Bhat, 2003).

In addition to bicycle facilities, bicyclist route choice behavior can be affected by other route attributes. Utilitarian or purposeful cyclists generally prefer fewer stop signs, red lights, and major cross streets (Sener et al., 2009; Stinson and Bhat, 2003). Many previous studies have emphasized the obvious importance of slope, turn frequency, and motorized traffic volume; that is, cyclists tend to avoid steep slopes, turns, and exposure to heavy traffic volume. Khatri et al.'s (2016) recent investigation of route choices made by users of Phoenix's (AZ) Grid Bikeshare system is a case in point. Specifically, they found that while both registered and casual users of the system valued routes with fewer left and right turns, casual users had a stronger aversion to routes with left turns most likely due to delays in turning left at both signalized and non-signalized intersections, not to mention the additional safety risk associated with left turns. The authors also found that traffic volume was associated with a negative utility for both types of users.

According to Hood et al.'s (2011) study, cyclists will choose to avoid a turn with a cost of < 0.17 km, and if the detour of avoiding climbing a hill 10 m high is no more than 0.59 km, cyclists will choose the detour. With regard to bridges, commuter cyclists prefer those without automobiles, those with a barrier between motorized and non-motorized traffic, or those without any special provisions for cyclists but connected to bike lanes (Stinson and Bhat, 2003). Few studies have explored the effects of on-street parking characteristics, such as presence of parking, parking type, parking occupancy rate, and length of parking area, on cyclist route choice. However, in Texas, Sener et al. (2009) found that cyclists prefer routes with no or minimal parking along the street, and discovered a preference of routes with angled parking among all the alternative routes with on-street parking.

Additional factors that affect cyclists' routes in terms of cyclist characteristics, such as age, gender, income, and cycling experience, are also explored in some studies. Lower income and younger respondents tend to make shorter commutes, and there is no significant relationship