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An optimization approach for equitable bicycle share station siting

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ABSTRACT

Bicycle share systems are becoming an increasingly popular feature of many urban areas across the United States. While these systems aim to increase transit mode options as well as overall bicycle ridership, bike share programs also face challenges and criticisms related to density and inequitable distribution of services. Key factors in the success of bicycle share include high station density as well as services that reach a variety of neighborhoods, though many current systems do not reach low-income areas. Equitable station distribution therefore appears to be a complex problem to address. We propose utilizing spatial analytics, including GIS and spatial optimization, to help site bicycle share stations across an urban region. Specifically we seek to apply a covering model to assess how many bicycle stations are needed, and where they should be located, so no user would have to travel too far for access. The city of Phoenix, Arizona, is used as a case study to illustrate the coverage and access tradeoffs possible through different investment strategies. Accordingly, for a given investment level, the set of stations is identified that provides the best access to the designated bike path network for the greatest number of potential users. Further, tradeoff options that differentially favor either network or population coverage are possible, and can be identified and evaluated through the proposed analytical framework.

1. Introduction

Cycling is associated with a range of individual and population-level benefits, including decreased risk of adverse health outcomes as well as reduction in carbon emissions typically associated with motorized traffic (Kuzmyak and Dill, 2014). Despite benefits, cycling rates remain low in the United States, representing around 1% of all trips (Kuzmyak and Dill, 2014). One avenue for increasing rates of cycling is for cities to adopt public bicycle share programs, providing on-demand access without the responsibility of ownership, eliminating the need for storage, and reducing risk of theft (Smith et al., 2015). In a typical community-based bicycle share model, users check out a bicycle from a kiosk or station for short-term rental and return it to another station (or the same station) after a short period of use (Fishman et al., 2013; DeMaio and Gifford, 2004). Contemporary versions of these programs require payment via credit card or smartphone application, and the bicycles themselves are equipped with tracking technologies that allow program operators to follow bicycle movement between stations (Fishman et al., 2013). If a user returns a bicycle outside the time allotted by the program, additional charges may be incurred (DeMaio and Gifford, 2004). Both of these features allow users and bicycles to be tracked and provide incentive against theft of equipment. Bicycle sharing programs have become increasingly popular in recent years, with over 600 cities worldwide currently in operation (Smith et al., 2015). Within the United States, adoption of bicycle share systems has been steady, with > 60 cities now having active programs.

1.1. Benefits of bicycle share programs

Incorporating bicycle share systems into the mode choices available to urban commuters has several potential benefits including increased active transport, a reduction in negative environmental impacts associated with motorized travel, and providing connection to other transit modes (Shaheen et al., 2010; DeMaio, 2009). Cities with low levels of cycling as a travel mode may have as much as a 1.5% increase in cycling activity after bicycle share programs are introduced (DeMaio, 2009). Further, cities with bicycle sharing have increased rates of transit use as connectivity to other modes increases. Commuters who already use public transit may opt to use a bicycle share program over transfers or walking to save time (Shaheen et al., 2010; DeMaio and Gifford, 2004). Connection to other public transit modes has the potential to aid the “last mile problem” (Shaheen et al., 2010) where commuters can arrive relatively close to a destination via transit, but might still be in need of additional transit support for distances that are

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too far to walk. Bicycle share activity is higher around public transit links, especially during peak hours, and many riders may use the bicycles to reduce overall travel times associated with transfers and backtracking that are necessary in some transit systems (Ricci, 2015; Fishman et al., 2013). Bicycle share stations with high activity are also associated with areas lacking public transport accessibility, suggesting that bicycle share can fill gaps in public transport along with the positive interaction potential with existing transport options (Fishman et al., 2014; Ricci, 2015).

A reduction in personal vehicle trips associated with increased bicycle trips has the potential to reduce greenhouse gas production, though overall modal shift in areas with bicycle share programs is necessary to realize this benefit (Shaheen et al., 2010; DeMaio, 2009). Specifically, the greatest benefit in terms of emissions would come from those bicycle share users who would otherwise use a personal vehicle and total motor vehicle miles travelled has been reduced with adoption of bicycle share (Ricci, 2015). Cycling as a transport mode is also associated with reduced risk of obesity, hypertension, and overall lower mortality (Buehler et al., 2016; Saunders et al., 2013). Those living near bicycle share stations tend to have increased cycling activity, with bicycle share use associated with lower body mass and reduced stress (Ricci, 2015).

1.2. Factors influencing bicycle share use

While there are clear benefits to integrating bicycle share within an overall public transport design, there are user-level factors that may determine whether systems are successful. Station location and density are among the most important factors in bicycle share system success; stations should be located close together so that users are not taxed with walking far distances to access the system while also giving riders increased options to connect with stations. Uniformly high density within bicycle share systems, or stations located approximately 1000 ft. apart or at a density of 28 stations per square mile, is associated with higher ridership overall (NACTO (National Association of City Transportation Officials), 2015). "Convenience" is often stated as a motivator for taking advantage of bicycle share; living in close proximity to a bicycle share station results in higher utilization, with walking as the most common mode that people use to connect to stations (Fishman et al., 2013, 2014; Fuller et al., 2011).

Density and distribution across different types of neighborhood types is also key in fostering bicycle share ridership, though equity in spatial distribution has been criticized in many North American systems (NACTO (National Association of City Transportation Officials), 2015). Bicycle share and other "active living" programs have targeted communities with higher socioeconomic status (Smith et al., 2015). There is risk of further marginalizing traditionally underserved populations if station distribution is not equitable across a region. Lower-income communities may be more likely to experience difficulties related to mobility and accessibility overall and tend to be underserved by bicycle share systems (Smith et al., 2015). Bicycle share is often not a convenient or accessible transport option in low-income neighborhoods as station density does not make it a practical choice among transport options (NACTO (National Association of City Transportation Officials), 2015). Despite lower bicycle station density in areas with lower socioeconomic status, users in those areas make a higher number of trips after controlling for station density and expanding systems into lower-income areas has led to increased ridership among low-income users (Ogilvie and Goodman, 2012; Goodman and Cheshire, 2014). This suggests that convenient access and visibility in low-income areas is crucial in developing both equity and increased ridership within bicycle share systems (Goodman and Cheshire, 2014).

One factor contributing to inequitable station distribution is that urban downtown development areas are ideal for short bicycle trips because of the density of transport destinations. Though it makes some sense to establish systems in areas where users are more likely to quickly adopt due to proximity and concentrated activity/attractions, such an arrangement will contribute to social inequity (Ricci, 2015). Distribution of stations among urban cores as well as throughout residential neighborhoods has the potential to resolve issues related to public transit linking as well as bicycle share system inefficiencies.

1.3. Bicycle share system design

There is a need for bicycle share system design approaches that ensure sufficient density and equitable distribution across a region to foster bicycle share success in terms of access, ridership, and efficiency. One approach is to optimize system design focused on impedance and coverage (García-Palomares et al., 2012). Minimizing impedance aims to locate stations across a study area so distance between stations is minimized, and maximizing coverage aims to locate stations where the most potential demand (population) is served. While such a modeling approach identifies good locations for stations within the study area based on specific model objectives and parameters, it has notable limitations. Coverage optimization ensures that the greatest amount of benefit is provided by the system in terms of serving demand, but does not account for social equity within that population in terms of income or other factors. In a similar vein, features of the study area such as parks neighboring areas of low population density will likely be underserved by approaches that focus solely on where people live, yet are still popular destinations for bicycle share users (García-Palomares et al., 2012). Another approach focuses on projected user demand and budgetary constraints to locate stations within travel zones (Frade and Ribeiro, 2015). While such approaches consider the fiscal realities of investing in and implementing bicycle share, the results do not identify the specific locations for the stations and consider only initial investment budgets. Both approaches rely on a priori knowledge of the number of stations to be installed or a budget that restricts the number of stations. Restricting the analysis of station location to a particular number of stations (or budget) may offer insight for the initial phase of bicycle share system installation, but system expansion would require subsequent analyses, lacking integration and would likely introduce system inefficiency (Church and Murray, 2009). An effective approach for system design would consider the optimal number and location of stations at a given service standard, and would identify how best to install these stations given a particular configuration.

The purpose of this paper is to develop a framework for locating bicycle share stations that are equitably distributed throughout a region in order to meet a given service standard for access. To this end, the specific objective was to identify a configuration of bicycle share stations that provide the best network and population coverage at a one-mile service standard for a given level of investment. If the desire is to ensure that no user would have to travel more than a half-mile to reach a station, and no more than one mile between stations, how many stations would we need and where should they be located? Starting from a plan of equal distribution across an area ensures that the level of density is achieved and that all areas receive service, regardless of neighborhood make up. Finally, there is a critical need for approaches with capabilities to assess and compare service provision in existing systems; in this way we improve on prior models by including assessment of tradeoff solutions for alternative station configurations. We outline our approach and results utilizing coverage modeling. Implementation and application for bike sharing in the City of Phoenix is reported, wherein we evaluate and characterize the current system and use our modeling approach to develop a reconfigured station arrangement with greater coverage.

2. Methods

2.1. Study area

Phoenix, Arizona is relied upon as a case study in our analysis.