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Bicycle sharing system design with capacity allocations

Dilay Çelebi*, Aslı Yörüsün, Hanife Işık

Istanbul Technical University, Department of Management Engineering, Macka, Turkey

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ABSTRACT

This study presents an integrated approach for the design of a Bicycle Sharing System (BSS) by jointly considering location decisions and capacity allocation. An important distinction of this approach is the definition of service levels, measured by the amount of unsatisfied demand both for bicycle pick-ups and returns. The method combines a set-covering model to assign location demands to stations with a queuing model to measure the related service levels. The key quality of this approach is its capacity in addressing the issues related to uncertainties in bicycle pick-up and return demand in BSS network design decisions. Results of the implementation of a BSS design for Istanbul Technical Universityâ;;s Ayazağa Campus show that our approach provides a balanced BSS network by equalizing the mean demand and return rates, which will decrease the need for relocation efforts once the system is put to use.

1. Introduction

Bicycle Sharing Systems are ideal for short distance point-to-point trips providing users the ability to pick up a bicycle at any self-serve sharing point and return it to any other point located within the system service area (Zhang et al., 2015). They are convenient in providing an alternative or complementary form of transport to cover short journeys, particularly in traffic restricted areas, such as parks, university campuses, and historic city centers. The fact that bicycles are a cheap and green form of transport, benefits of a Bicycle Sharing System (BSS) include flexible mobility, emission reductions, increased physical activity, reduced congestion and fuel use, individual financial savings and support for multi-modal transport connections (Shaheen et al., 2010).

The evidence from different cities and countries suggests that bicycle sharing can improve the experience, accessibility and affordability of personal travel, through greater transport choice, reduced journey times and reduced mobility costs (Ricci, 2015). Nevertheless, an efficient design of a BSS is vital to prevent critical issues that may lead to shortcomings. For example, despite the high rate of bicycle usage in Beijing, some BSS companies declared bankruptcy and were closed; others closed dozens of bicycle stations to reduce the operational costs in 2009 (Liu et al., 2012). Similarly, in Melbourne the public BSS have had disappointing usage rates despite the significant increase in bicycle use as transportation in Australia over recent years (Fishman et al., 2012). To prevent failures and to minimize the negative impacts of obstacles and uncertainty, a BSS design should address the key success factors for an efficient running of the system, such as future demand, the distribution of bicycle stations, capacity management and the charging mechanism. The key motivating factor for bicycle sharing use is the convenience that users can have access to the service whenever and wherever needed, and that the service is not interrupted because of bicycle shortages or unavailability of empty slots for returns.

* Corresponding author.
E-mail address: celebid@itu.edu.tr (D. Çelebi).

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Alvarez-Valdes et al. (2016) defines three phases in the design and operation of a bicycle sharing system. They suggest that the number of stations and their locations have to be decided in the first stage, the number of bicycles in the system has to be determined in the second stage, and a bicycle repositioning system has to be adopted for moving bicycles from stations with an excess to stations with a shortage in the final stage. Nevertheless, the first two steps are highly interdependent. The proximity of residence to docking stations is strongly correlated with frequency of use – accordingly, demand for both bicycle rentals and returns at any station is determined by the convenience of its location and range of its coverage. On the other hand, each bicycle station must carry enough capacity to increase the probability that users can find a bicycle or a docking station when needed.

The model proposed in this paper addresses a station based BSS offering spontaneous one-way trips with a flat subscription fee. Reservation of bicycles is not possible. We developed a mathematical model and a solution method for determining the number and location of the required stations of such a BSS by taking into account the service levels. We also present an application of the proposed model for planning a BSS for Istanbul Technical University's Ayazağa Campus. The remainder of the paper is organized as follows: Section 2 reviews the different research approaches on BSS design and discusses how they relate to the objective of this work. Section 3 presents the model and the method for determining optimal station locations and capacities. Section 4 explains the application of the proposed model, including estimation of bicycle sharing demand and then translating it into transport flow patterns. Section 5 concludes the study and outlines perspectives for further research.

2. Review of BSS models

A BSS is defined as a system offering short-term urban rental bicycles available from a network of unattended locations in public spaces. Users arrive at rental stations, utilize the bicycle for some period of time, and then return it to the station of their choice (George and Xia, 2011). Three (and a half) generations of bicycle sharing systems can be identified (Vogel and Mattfeld, 2010): The first generation originates in Amsterdam in 1965. The initiative was called "White Bicycles" where bicycles in circulation were provided free to be used for one trip and then left unlocked for someone else to use. Second-gen BSS emerged in Copenhagen, under the name "Bycykler København". The system introduced the coin-deposit model to deter theft and to encourage bicycle returns. Yet, the program still had an issue with theft due to the anonymity of the users. The third generation replaced coin-access with smart card access. It was first launched in Rennes as âVelos a la carte It also started the restricted usage time scheme, generally providing 30 min of bicycle use for free. The next generation (3+) of bicycle sharing systems was smartened with real-time availability and GPS tracking. These systems signal the appearance of flexible, clean docking stations, touchscreen kiosks, additional bicycle re-balancing technologies, as well as the integration of a unique individual card allowing a user to make use of both bicycles and public transportation. Currently, there are around 1000 cities equipped with BSSs around the world (Wikipedia, 2017).

BSSs have been receiving growing attention from researchers and policy makers for achieving more sustainable urban transport (Lovelace et al., 2011). Over the past decade, bicycle sharing has become more common, consequently a good inventory of research has been developed for the analysis of BSSs in towns and cities around the world. Some examples are Dublin (Murphy, 2010), Madrid (García-Palomares et al., 2012), Beijing (Liu et al., 2012), Montreal (Bachand-Marleau et al., 2012), Brisbane (Fishman et al., 2012), Helsinki (Jäppinen et al., 2013), Paris (Nair et al., 2013), Milan (Croci and Rossi, 2014), Coimbra (Frade and Ribeiro, 2015), Palma de Mallorca (Alvarez-Valdes et al., 2016), Taipei City (Yan et al., 2017), Switzerland (Audikana et al., 2017), and New York (Campbell and Brakewood, 2017).

Many of these studies provide a quantitative analysis of existing BSSs, examine empirical evidence of the usage patterns, and analyse the characteristics of these systems through quantitative metrics. Jäppinen et al. (2013) studied the impacts of a BSS on public transport travel times in Greater Helsinki and concluded that a BSS should be viewed as part of public transport rather than a separate cycling scheme. García-Palomares et al. (2012) identified and critically interpreted the available evidence on bicycle sharing to date, on both impacts and processes of implementation and operation. Croci and Rossi (2014) analysed the case of Milan to assess the factors that influence the use of bicycle sharing stations and examined the different effects of proximity and visibility of bicycle sharing stations of those factors. Zhang et al. (2015) explored the characteristics and commonalities between particular bicycle sharing systems in urban areas in an empirical study in China. Fishman et al. (2013) provided a critical examination of the growing body of literature in an overview of bicycle share programs. An extended review of the enabling conditions for the occurrence and transferability of beneficial impacts of a BSS can be found in Ricci (2015).

One stream of literature focuses on strategic design and the logistics of BSSs regarding the capacity and locations of bicycle rental stations to optimize a measure or a combination of measures for system performance (Boyacı et al., 2015). These studies aim at determining the number and location of stations, total fleet size, and/or the structure of the network of bicycle paths that should be developed to connect the bicycle stations. George and Xia (2011) developed a closed queueing network model for determining optimal fleet size through the use of a profit-based optimization problem. Nair and Miller-Hooks (2016) used an equilibrium network design model to determine locations of a given number of bicycle sharing stations that maximizes the flow potential along bicycle sharing links. Reijsbergen (2016) used spatial data to identify alternative locations in the target city and used simulation techniques to determine how attractive those areas are for station placement. Yan et al. (2017) applied a time-space network technique to formulate four planning models for leisure-oriented public bicycle rental systems under deterministic and stochastic demands for locating stations, fleet allocation and bicycle