Transportation Research Part E 116 (2018) 59–69

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Performance analysis of a hybrid bike sharing system: A service-level-based approach under censored demand observations

Szymon Albiński*, Pirmin Fontaine, Stefan Minner

Technical University of Munich, School of Management, Arcisstraße 21, 80333 Munich, Germany

ARTICLE INFO

Keywords:
Bike sharing
Hybrid bike sharing system
Data analysis
Censored demand
Service levels

ABSTRACT

We investigate a hybrid bike-sharing system. We carry out a usage pattern and demand analysis on the booking data of the system and include the effects of censored demand in a service level analysis. Service levels are used as meaningful measures for evaluating the customer-oriented performance of bike-sharing systems. Our results show that service levels are overestimated when ignoring unobservable, censored demand effects. Furthermore, there are significant differences between free-standing and station-based bikes. Based on these results, an adjusted incentive and reposition policy could increase the booking number of free-standing bikes and thus customer satisfaction as well as the system's profitability.

1. Introduction

The ongoing urbanization overstrains the traffic networks and leads to congestion. Therefore, more and more cities promote the use of the bike as an alternative transportation mode. In a city with a well-developed bike infrastructure, the bike can even be the fastest option to travel (e.g., Leth et al., 2017; Faghih-Imani et al., 2017). Besides the time saving, the health aspects and the reduction of emissions are other key benefits of the increasing popularity of bike sharing systems (DeMaio, 2009; Fishman et al., 2013).

While the available infrastructure forms the basis, the boom of biking can also be attributed to the growing number of bike sharing systems around the world. The first bike sharing system, the white bikes of Amsterdam, was introduced as early as in 1965, but it no longer has many things in common with bike sharing systems as we know them today (DeMaio, 2009). In 2017, more than 1200 cities were operating bike sharing systems (The Bike-sharing World Map, 2017) and the number is still growing as cities want to earn the reputation of being green and environment-friendly. While bike sharing provides an additional option for the local population to get to work or to the places of their leisure activities, tourists tend to use these bicycles spontaneously for exploring the city.

Most systems in Europe and North America are station-based systems where bikes are rented at predefined stations and also returned to a station after usage.

Free-floating systems offer a higher degree of flexibility to the customers as bikes can be parked anywhere inside the operating area and no stations exist. In the last years, hybrid models, too, e.g. Norisbike in Nuremberg or the MVGRad in Munich, were introduced. In these systems, the bikes can be parked and rented everywhere inside the operating area. Additionally, several stations where bikes can be rented and returned are placed throughout the city. The stations have two key functions: (1) The battery of the bike's radio module can be recharged if the bike is connected to a station. Since the battery can only be loaded during a ride, this may become a necessity for those bikes that have been sitting idle for a longer period. (2) The positioning of such stations at public transport stops or points of interest guarantees a better availability of bikes at highly frequented locations. This makes the system

* Corresponding author.
E-mail addresses: szymon.albinski@tum.de (S. Albiński), pirmin.fontaine@tum.de (P. Fontaine), stefan.minner@tum.de (S. Minner).

https://doi.org/10.1016/j.tre.2018.05.011
Received 14 November 2017; Received in revised form 26 April 2018; Accepted 25 May 2018
1366-5545/

more attractive to customers, as the search for bikes can be time-consuming even if smartphone apps indicate the position of bikes on a map.

The success of a bike sharing system depends on many factors. For the users, the availability of functional bikes and the price are the key aspects. The operators, on the other hand, want to maximize their revenues. Typically, the demand varies for different areas of the city. Even more, the inflows into and outflows from several areas are often imbalanced. To maintain availability, the operators have to reposition the bikes by using shuttles. The operations planning is based on the analysis of the customers' demand patterns. Since the repositioning is cost-intensive but fosters the number of rentals, the operator has to continuously determine the optimal number of repositioning operations in a dynamically changing system.

While for station-based bike sharing systems the literature on demand analysis and repositioning operations is broad (see, e.g., DeMaio, 2009; Fishman et al., 2013), hybrid systems have not been studied so far. Compared to a station based system, the operational costs of a hybrid system can be higher if too many bikes need to be collected and returned to stations for recharging. Using a real-world data set, we analyze demand patterns in a hybrid system and identify important strategic decisions in such a system. We show different behaviors dependent on the location in the city and whether or not the demand originates from a station or from a free-standing bike.

So far, the performance of a bike sharing system is measured by the total number of trips. We use service level approaches from supply chain management to quantify both the potential of demand as well as the performance of the system in terms of stock-outs, since these measures can better reflect the satisfaction of customers. Moreover, the literature neglects the fact of censored demand. If a station is out of stock, the true demand might be higher and forecasting models might underestimate the actual demand. We want to fill this gap by including censored demand in our analysis.

Our contribution is (1) a performance analysis of a hybrid bike sharing system based on service level measures and using real data, (2) evaluating the effect of censored demand observations that leads to service level overestimation if being neglected, (3) suggestions for operators how they can increase the profitability of hybrid bike sharing systems by combining the advantages of the station-based and free-floating bikes.

The remainder of the paper is structured as follows: The literature is summarized in Section 2. In Section 3, we describe the hybrid bike sharing system and the used data. Section 4 introduces the performance measures and shows how censored demand observation were corrected. The results of our analysis are presented in Section 5. Based on these results, we deduce several managerial insights in Section 6. In Section 7, we summarize our findings and give an outlook for future research.

2. Literature review

The literature on bike sharing can be divided into two main streams: demand analysis including forecasting (e.g., Froehlich et al., 2009; Vogel et al., 2011) and redistribution of bikes (e.g., Neumann-Saavedra et al., 2016; Raviv et al., 2013; Rainer-Harbach et al., 2013; Ho and Szeto, 2014; Caggiani et al., 2018). Because of unbalanced demands, the repositioning of bikes improves both the profitability of a system and the customer satisfaction. The basis for all these operational models is the analysis of demand patterns and a forecast of demand for deriving the operational decisions. DeMaio (2009) and Fishman et al. (2013) give an overview of the literature on bike sharing systems.

For a station-based system, Froehlich et al. (2009) show a spatio-temporal analysis of Barcelona's bike sharing system. By analyzing the number of bikes at stations, they identify different demand patterns over the day and behavioral patterns in different areas by using clustering techniques. The results are used for predicting the number of available bikes at each station. For the same system, Kaltenbrunner et al. (2010) use regression analysis to predict the number of bikes at stations some minutes before the occurrence. The dependency of demand on weather conditions is analyzed for the bike system in Lyon by Borgnat et al. (2011). Moreover, bike flows are clustered between stations to identify spatial patterns. For the bike sharing system in Vienna, Vogel et al. (2011) identify five different types of stations depending on the demand over the day. An extensive investigation of 38 station-based systems both for the bike sharing system infrastructure and the usage patterns is performed by Brien et al. (2014). Recently, Fishman et al. (2015) analyzed the factors that influence the decision for a bike share membership in Melbourne and Brisbane and identified important factors that can increase the demand. The impact of land-use and urban form (Faghih-Imani et al., 2014) and the influencing factors of bike sharing system infrastructure (Faghih-Imani and Eluru, 2016) were investigated for the BIXI system in Montreal. For the New York CitiBike system, Faghih-Imani and Eluru (2016) show a strong dependency of arrival and departure rates on spatio and temporal factors. Further, Faghih-Imani et al. (2017) give insights into such influencing factors like socio-demographic characteristics, the bicycle infrastructure, and land-use characteristics for arrival and departure rates at bike stations based on a data set from Barcelona and Seville.

The strategic design of a station-based bike sharing system is studied by Lin and Yang (2011). They propose a mixed-integer linear model for positioning stations and opening bike lines such that pre-defined service levels at the stations are met. Pfrommer et al. (2014) develop a model that combines operator-based and customer-based repositioning of bikes in London. The prices are computed dynamically and the aim is to incentivize customers towards returning bikes to nearby under-used stations. These relocations are complemented by operator-based repositioning. Waserhole and Jost (2012) use a fluid approximation model for controlling the balance of vehicle sharing systems exclusively through the adaptation of prices. For free-floating bike sharing systems, Reiss and Bogenberger (2015, 2016a,b) use the data of Munich's "Call a Bike" operated by the German Railway. They analyze temporal patterns and combine and evaluate operator-based and user-based relocation strategies. Ho and Szeto (2014) propose Tabu Search for solving the rebalancing problem in a station-based system. Regue and Recker (2014) present a four step approach for repositioning bikes proactively. This includes demand forecasting, a station inventory model, a redistribution model and a routing model for the service