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Bike-sharing stations: A maximal covering location approach

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ABSTRACT

The promotion of sustainable alternatives to motorized individual mobility has been seen in the past few decades as one of the cornerstones in a strategy to reduce the negative externalities related to the transportation sector. Bicycle sharing is increasingly popular as a sustainable transport system and the number of bike sharing schemes has grown significantly worldwide in recent years. One of the most important elements in implementation of these systems is the location of the stations. In fact the non-optimal locating of bike sharing compromises its success.

Municipalities or public–private partnerships are mostly responsible for implementing bike-sharing schemes. The public investment in bicycle mobility (particularly bike-sharing) is complex because it is always subject to a budget. The main concern for public investment is to maximize the benefits through the design and implementation of bike-sharing systems. This work sets out a methodology to help with the decision-making of bike-sharing systems.

The research work we present proposes using an optimization method to design the bike sharing system such that it maximizes the demand covered and takes the available budget as a constraint. It combines strategic decisions for locating bike-sharing stations and defining the dimension of the system (stations and number of bicycles) with operational decisions (relocating bicycles).

As an outcome, the model determines the optimal location of the bicycle stations, the fleet size, the capacity of the stations and the number of bicycles in each station, considering an initial investment lower than the given budget. In addition, it balances the annual cost of the system and the revenue assuming a possible supplementary budget from the system provider to cover any loss resulting from the shortfall between its operating cost and the revenue from the subscription charges.

A case study in Coimbra, Portugal, is presented and discussed.

1. Introduction

1.1. Bike-sharing systems

The first bike sharing system emerged in Amsterdam, the Netherlands, in 1965. Nowadays, a number of cities around the world have adopted public bicycle sharing systems as a transport option. According to the Bike Sharing World Map,[2] there are 813 bike-share programs in operation worldwide and 221 being planned or under construction.

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[2] The Bike-sharing World Map is provided by MetroBike, LLC based in Washington D.C. USA. It shows the bike-sharing systems all over the world and gives some basic information about them. See at: www.bikesharingworld.com, accessed in December 2014.

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The service includes picking up and dropping off a bicycle at different stations in an urban area, in coordination with other transport modes.

Four generations of bike sharing systems can be identified: free bikes, coin-deposit, information-technology-based and multimodal systems. The most recent generation of bike-sharing systems is demand-responsive and adapts the service to user needs. It considers the most recent improvements in technological mechanisms at the stations, bicycles that are easier to use and share, electric bicycles, bicycle relocations and the inclusion of several transport modes on the same access card (public transportation and car-sharing) (Demaio, 2009; Shaheen et al., 2010). The bike-sharing programs developed around the world in recent years are mainly based on third generation systems.

One of the most popular and extensive bike-sharing programs is Vélib' in Paris (France). It consists of a network of 1800 stations (a station every 300 m), and more than 20,000 bicycles are always available. China has the largest bike-sharing market. For example, Hangzhou city hall launched a public bicycle sharing system in 2008, the Hangzhou Public Bicycle. In 2011, the scheme had 60,600 bicycles with 2416 fixed stations, one every 200 m, in eight core districts (Shaheen et al., 2010). A 'user key' is needed to unlock the bicycles in the station and this is generated by inserting a credit card.

Most systems offer a choice of subscriptions: short-term subscription (1-day, 3-day or 7-day ticket), or long-term subscription (monthly or annual). Such systems have an important environmental impact by cutting energy dependence and decreasing greenhouse gas emissions and therefore they can help improve public health. They also have a positive impact on reducing car use. Furthermore, the implementation of bike-sharing schemes promotes private bike use itself and greatly enhances the image of cycling (Demaio, 2009; Fishman et al., 2014; Woodcock et al., 2014). In terms of strategic planning, bike sharing systems can be seen as a useful tool to improve the quality of city life and the urban environment by making better use of urban spaces (European Commission, 1999).

One of the most important elements in the implementation of these systems is the location of the stations. If they are poorly located, this compromises the success of the system. Bike-sharing systems are mostly introduced by municipalities or by public–private partnerships. Since public investment in bicycle mobility (particularly bike-sharing schemes) is always subject to a budget, the main concern for public investment is to maximize the benefits at the design and implementation stages. In this paper, we present an optimization model designed to determine the location of bike-sharing stations, assuming budget constraints but maximizing the demand covered. It could be a good tool to help urban managers implement a bike-sharing system by making the investment as effective as possible, and it represents innovation in this matter.

1.2. Literature review

Facility location is a strategic decision that depends on its preliminary goals. Locations can be selected efficiently with the support of a particular type of optimization model, called facility location models, whose decision variables represent the location, the capacity, the coverage area of any kind of facility, and, in this case, the relocation of bicycle stations (Daskin, 1995; Daskin, 2008; ReVelle and Eiselt, 2005).

Several objectives can be considered in a facility location model such as the minimization of the overall cost, the minimization of transportation costs, and the maximization of demand coverage. The first objective is dealt with through fixed-charge models, the second through p-median models, and the third through maximal covering models. Depending on whether capacity constraints apply to the facilities, the models are classified as capacitated or incapacitated.

In the case of bike-sharing stations, the literature reports different approaches to tackling the location of the stations with facility location models.

An optimization model is described in Lin and Yang (2011) who propose an integer nonlinear program that determines the optimal location of docking stations, the bicycle lanes needed and what routes should be taken from each origin to each destination. It is based on cost minimization and assumes a penalty for uncovered demand. This model does not consider the relocation of bicycles; it assumes that bicycles and free spaces are always available in the stations, but this oversimplifies the problem.

The model presented in Lin et al. (2011) incorporates bicycle stock considerations and is formulated as a hub location inventory model. The formulation presented is not computationally tractable and the authors propose a greedy heuristic method to efficiently find near-optimal solutions.

A mixed-integer linear program performed through a heuristic that optimizes the location of shared bike stations is presented in Martinez et al. (2012), assuming a fleet size and bicycle relocation calculation for a regular operating day. The main purpose of the method is to maximize revenue.

The literature contains other methodologies to define the location of the stations, without facility location models.

The authors of Romero et al. (2012) consider a simulation–optimization method that relates public bicycles to private cars. The methodology is essentially a bi-level mathematical programming model that optimizes the location of public bicycle stations.

A GIS-based methodology to estimate the potential trip demand and its spatial distribution, the location of the stations (using location-allocation models), the station capacity and demand profiling for stations is proposed in García-Palomares et al. (2012). Both the simple location problem and the relocation must be taken into account, and this balance of the bike-sharing systems problem, which considers the number of bicycles in each station and the optimal relocation routes, is discussed in Lu (2013), Raviv and Kolka (2013) and Sayarshad et al. (2012). The first, Lu (2013), sets out a robust fleet allocation model that generates the optimal daily allocation of bicycles to the stations and the redistribution flows of an