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# Inventory Routing for Bike Sharing Systems

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## Abstract

Bike sharing systems have been launched in many cities. Such systems consist of stations allowing users to rent and return bikes. Due to spatio-temporal variation of requests, stations tend to either be empty or full of bikes. At empty stations, no bikes can be rented while at full stations bikes cannot be returned. The global goal is to satisfy all rental and return requests anytime at any station. To meet the goal, a fleet of transport vehicles relocates bikes between stations to realize suitable fill levels.

We present a multi-periodic inventory routing problem on the operational management level of bike sharing systems. Here, we take into account both time-dependent requests and target fill levels. The request structure is offered by data analysis. Target fill levels are given by optimization models on the tactical management level. The objective is to minimize the deviation of realized fill levels and target fill levels subjected to capacity and time constraints. Due to the large number of possible solutions, instances are solved by a two-dimensional decomposition approach. First, the given periods are solved independently. Second, in each period the set of stations is divided into disjoint subsets. Each subset is assigned to one vehicle. Appropriate subsets are generated by local search algorithms. Subsets are evaluated by a cost-benefit routing algorithm.

For computational studies, we use real-world data of Vienna's bike sharing system "CityBike Wien". Our results depict that appropriate subsets allow efficient routing and relocation of bikes and thus, target fill levels can be realized.

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*Keywords:* inventory routing; local search; shared mobility; bike sharing

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## 1. Introduction

Cities deal with a large volume of traffic resulting in traffic jams and environmental pollution, e.g., noise and carbon dioxide emission. One approach to tackle these inconveniences is the use of public bike sharing systems (BSS, Büttner et al., 2011). Most BSS consist of stations, where users can rent and return bikes ad hoc. Further, station-less systems exist, where bikes are parked anywhere in the city center while they are not rented (Shaheen et al., 2010). Regarding rental requests, station-based systems seem to be advantageous since users can always rent bikes at the same stations according to their habits. In station-less systems, every time a user wants to rent a bike, the nearest bike has to be located, e.g., via smart phone app. Regarding return requests, station-less systems seem to be advantageous since users can return bikes almost anywhere. In station-based systems, bikes have to be returned at stations.

To ensure that users can rent and return bikes anytime at any place, providers aim to provide sufficient numbers of bikes and free bike racks at all stations throughout the day in a cost efficient manner. Here, providers face several challenges. Due to the short trip duration, requests are uncertain. Further, bikes are not returned at the station they have been rented at and so stations may tend to either run full or out of bikes. Moreover, the structure of user request is subject to spatio-temporal variation. Thus, the request behavior for every station differs in the course of the day. To satisfy as many requests as possible, the BSS has to be designed and maintained to match these challenges.

For station-based BSS, the challenges can be proceed on the strategical (long-term), tactical (mid-term), and operational (short-term) management levels (Vogel, 2016). The strategic management decides about locations and capacities of stations. On the tactical level, optimal fill levels for each station and for (hourly) periods throughout the day are determined by analyzing recorded data on single trips. Each trip consists of a rental and a return request. For each request, the associated station and the time it takes place are given. The determined fill levels anticipate typical user behavior and serve as input for operational planning. To realize these target fill levels, we distinguish two options. An indirect option focuses on user-based relocation of bikes initiated by financial incentives. Here, users are granted a price reduction if they rent or return a bike in a defined area or at a defined station respectively (Ruch et al., 2014). A direct option draws on vehicles which are routed between stations to pick up and deliver bikes (Shaheen et al., 2010). We state the direct option suits station-based BSS well since stations allow relocating bulks of bikes with only one stop. In a station-less system, vehicles would have to stop for every bike to pick up. Thus, we assume vehicles in a station-based system to allow most efficient relocations to realize target fill levels. Nevertheless, 30% of the running costs (between 1,500 and 2,500€ per bike and year) are caused by relocations (Büttner et al., 2011). Thus, providers aim for efficient relocations. If not stated otherwise, from here on we focus on station-based BSS and direct relocations.

The target fill levels are real-valued and, therefore, not suitable for operation planning. Hence, fill levels are enlarged to fill intervals with integer bounds. Generally, not every target interval can be realized due to capacity and time constraints. The resulting deviations of realized fill levels and given target intervals are called gaps. We assume a high probability of unsatisfied rental or return requests in the presence of large gaps. Thus, the objective is to minimize the squared gaps over all stations. Then, large gaps are mostly avoided while small gaps are allowed.

In this article, we model the problem on realizing target intervals as a multi-periodic inventory routing problem (IRP). Within each period, decisions considering the served stations, the amount of transported bikes, and the according vehicle routing have to be made. For this problem, decisions impact the current and following periods. Due to the interval representation of fill levels, the model allows stations to be both source and sink, and even balanced stations to be used to reduce gaps of adjacent stations. Since this rich IRP cannot be solved to optimality within reasonable time, we apply a temporal and spatial decomposition approach. Temporal decomposition is applied using a rolling horizon, i.e., time periods are solved independently. Within each period, a spatial decomposition is applied. To this end, the set of stations is partitioned into disjoint subsets. Efficient subsets consider both short distances between stations and a balance in bike surpluses and shortages. The subsets are assigned to vehicles and evaluated by a cost-benefit routing algorithm. We test the approach with real-world data from Vienna's BSS "CityBike Wien" operating on 59 stations. The required target fill levels are provided by Vogel et al. (2014). We examine the results regarding the search operators, the local search algorithms, and the number of vehicles. Our results depict, that our approach offers suitable subsets where the target intervals can mostly be realized. Only in the rush hour a few stations remain imbalanced.