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Short-term strategies for stochastic inventory routing in bike sharing systems

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Abstract

Bike sharing systems (BSS) provide individual and eco-friendly urban mobility and are implemented in a growing number of cities. In BSS, customers can rent and return bikes spontaneously at stations and at every time of the day. To allow a reliable usage, system operators have to enable a sufficient number of bikes and empty bike racks at each station. Therefore, system operators use a set of vehicles to relocates bikes between stations. The according routing can be derived solving an inventory routing problem (IRP). For planning, operators can draw on expected customer trips generally following specific daytime patterns. Nevertheless, a significant amount of rentals and returns occur unpredictably and spontaneously forcing immediate adaptions of the routes.

In this paper, we define the stochastic IRP for BSS and present a short-term relocation strategy (STR). A STR defines priority stations regarding their urgency that have to be rebalanced. In a real world case study, we compare STR to a long-term relocation strategy (LTR) using given target fill levels. STR outperforms LTR significantly leading to suitable service levels.

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1. Introduction

Due to urbanization, the volumes of individual motorized traffic increase in cities worldwide (McCarthy and Knox, 2005). The results are traffic jams and environmental pollution. To reduce the number of motorized vehicles, city authorities draw on public transport and shared mobility systems. In particular, public bike sharing systems (BSS) are implemented to allow individual and eco-friendly transportation (Büttner et al., 2011). In BSS, a set of stations is distributed in a city. Each station contains a number of bike racks and bikes. At every station, users can rent and return bikes spontaneously. Typically, rental and return stations are not identical, i.e., one-way trips are usual. Due to spatio-temporal variation of user requests, stations tend to run full or out of bikes in the course of the day (Vogel et al., 2011). Further, due to the spontaneous and uncertain rental and return behavior, arbitrary stations might run empty or full unpredictably. Empty and full stations lead to failing user requests. At empty stations, requests for

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bikes cannot be satisfied while at full stations, requests for empty racks cannot be satisfied. A failed request leads to customer dissatisfaction and even a rejection of the whole BSS concept. So, system operators have to ensure a sufficient number of bikes and empty bike racks at each station for each point in time to reliably satisfy user requests. To achieve a sufficient service level, i.e., a high percentage of fulfilled customer requests, the system operator relocates bikes between stations with a fleet of vehicles. So, the system operator has to decide about the stations to serve and the number of bikes to relocate.

The presented problem can be formulated as an inventory routing problem with unknown due dates. Given a set of stations and inventory fill levels, the dispatcher routes capacitated vehicles between the stations. Inventory decisions are made about increasing or decreasing fill levels at each station to avoid customer dissatisfaction. A dissatisfaction occurs if a customer requires an inventory item (bike) or an empty inventory space (bike rack). Customer requests induce due dates for every station. A due date is the latest time a station's fill level can be adapted in order to fulfill requests. A due date is violated if the inventory is empty or full and an according request occurs. Since requests are uncertain, due dates are unknown as well. The objective is to minimize the number of due date violations over the planning horizon.

For planning, system operators can draw on current fill levels in stations and on expected future trips offered by data analysis (Borgnat et al. 2011, Vogel et al. 2011). A trip consists of one rental request and one return request. Furthermore, external information systems provide target fill levels as input for IRP (Schuijbroek et al. 2013, Vogel et al. 2014). These target fill levels are anticipatory, since information about expected future requests are considered. E.g., high target fill levels are determined if a high number of bike requests is expected. Target fill levels can be realized by transport vehicles (Raviv et al. 2013, Kloimüllner et al. 2014, Brinkmann et al. 2015).

In this article, we study the trade-off between the number of served stations and the ration of relocation operations and served stations. Thus, we introduce a short-term relocation strategy (STR). This strategy selects stations regarding their urgency and their immediate violation risk without making use of expected future requests. We compare the short-term relocation strategy with the long-term relocation strategy (LTR) by Brinkmann et al. (2015), which realizes anticipatory target fill levels given by Vogel et al. (2014). There are notable differences between STR and LTR: Firstly, STR neglects information about future requests while LTR rests upon expected requests offered by data analysis. Secondly, STR serves many stations and relocates a small number of bikes at each served station while LTR serves a small number of stations and relocates a large number of bikes at each served station. In a real world case study, we show that for the given problem, STR allows a substantially higher service level reducing the number of due date violations up to 72.52%.

This article is structured as follows: In Section 2, we refer to literature on both vehicle routing and bike sharing systems. A definition of the inventory routing problem in bike sharing systems is given in Section 3. The short-term and the long-term relocation strategies are introduced in Section 4. In Section 5, real world case studies are presented. This work concludes and gives an outlook of possible future work in Section 6.

2. Literature Review

The literature on vehicle routing and inventory management problems is vast. In vehicle routing problems (VRP), a fleet of vehicles moves between customer locations. The objective typically is to visit each location once within minimum time (Laporte, 1992), or to visit as many locations as possible within a limited time horizon (Ulmer et al., 2015). A multi-periodic VRP with due dates is described by Archetti et al. (2015). Here, a due date is the latest time a customer has to be served. All due dates are known in advance. Inventory management problems try to satisfy a given consumption while minimizing variable inventory and fixed order costs. A combination is introduced by Dror et al. (1985) and is called inventory routing problem (IRP). In an IRP, capacited vehicles serve customers. Each customer has a certain consumption of a commodity. The challenge is to provide the commodity in order to satisfy each user's consumption. Here, costs regarding transportation, inventory, and/or unsatisfied requests have to be minimized. A large overview of different IRPs is provided by Coelho et al. (2014).

The literature on BSS focuses on decision support for system operators. A system has to be installed and maintained to guarantee its functionality at all times in a cost efficient way (Benchimol et al., 2011). Literature on BSS can be divided into two groups. The first group aims on data analysis and optimization for determining optimal fill levels. Data analysis offering insights into general BSS behavior has been done by Borgnat et al. (2011) and Vogel et al.