Lecture Notes in Mobility

Jan Brinkmann

Active Balancing of Bike Sharing Systems

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Foreword

Vehicle sharing has received a remarkable attention as a new means of urban transportation. Practice has shown that the one-way use of vehicles follows mobility patterns of people leading to temporal and spatial imbalances with respect to the distribution of vehicles in the city. In station-based bike sharing systems, customers suffer from the absence of bikes in case of a potential rental and the absence of bike racks in the case of a bike return. Station-less systems have claimed to offer flexibility; however, they have failed to overcome the deficiency of bike imbalances.

System operators see the requirement of redistributing bikes between city areas over the day at significant expenses. A methodological support of bike logistics has concentrated on static optimization models. These models are typically fed with data of historic bike usage. Since history does not repeat itself, optimal solutions obtained from static model cannot be implemented due to stochastics with respect to actual bike usage.

Jan Brinkmann focuses on a control approach deciding dynamically about bike imbalances to be resolved. He combines control with an anticipation of future redistribution demand by means of online simulation. The simulation takes into account the driving time needed to arrive at the respective station, the loading or unloading time at this station as well as the avoidance of future fails resulting from bike inventory changes.

The informative value of the simulation strongly depends on the simulation horizon. A short horizon may not reflect the utility of the station visit. Simulating over a long horizon may report on customer fails, which no longer relate to the respective station visit. Jan Brinkmann is able to provide evidence that a suitable simulation horizon is by no means fixed, but depends on the particular situation, i.e., the time of day. To this end, he develops an approximate dynamic programming approach determining heterogeneous simulation horizons iteratively.

The above consideration applies to the one vehicle case only. Whenever a fleet of trucks is employed for bike redistribution, the decentral decisions of the trucks are no longer independent of each other. Since all of them follow the same decision model, it may happen that demanding stations may accidentally be visited multiple times. Jan Brinkmann suggests different levels of coordination coming along with a slightly growing need for information exchange. The trucks operate independently of each other and take decision for their own operation. Like in the one vehicle case before, decisions comprise the number of bikes to be loaded or unloaded at the current station and the station to be visited next.

The control approaches developed are carefully validated for real-world instances of bike sharing systems. Promising results are obtained for all instances considered. In particular, the approach is best suited for bike sharing systems which do not show a regular structure of bike imbalances due to commuter travel. Regular flows from residential areas to office districts in the morning and reverse flows in the late afternoon are relatively easy to predict and to counteract. More challenging are complex mobility patterns consisting of mixed work, shopping, and leisure activities. Results obtained indicate that these complex interactions can be supported much better by control than by static optimization.

Jan Brinkmann pioneers online control models for the redistribution logistics of bike sharing systems. The work bases on a solid understanding of bike sharing system, business models, and related activities. The control approach pursued has been well received by the transportation research community as well as by colleagues working in Operations Research. This book summarizes research of recent years by giving a comprehensive introduction into control approaches for today's and forthcoming vehicle sharing systems.

Braunschweig, Germany
January 2019

Dirk C. Mattfeld

Preface

Many cities suffer from discomforts caused by individual and motorized traffic. Therefore, city administrations implement sustainable shared mobility services such as bike sharing systems (BSSs). In BSSs, users are allowed to rent and return bikes on short notice at stations. Data analysis reveals that rental and return requests follow spatio-temporal patterns such as commuter usage and leisure activities. In the morning, commuter usage is indicated by mainly rental requests in residential areas and mainly return requests in working areas. This behavior inverts in the course of the day. The resulting unequal requests lead stations to become empty or full. Requests to rent bikes will fail at empty stations. At full stations, requests to return bikes will fail.

Providers counteract these inconveniences by means of balancing. In this work, we focus on the operational management's view on the balancing of BSSs. That is, the provider schedules transport vehicles relocating bikes between stations in order to minimize the amount of failed requests. As requests are uncertain, the resulting challenge is to identify stations with a lack or a surplus of bikes. To this end, we introduce approaches simulating future requests and approximating expected amounts of failed requests. Then, anticipation is enabled by means of including the approximations in the decision making process.

We evaluate our approaches in case studies based on real-world data. The results point out that our approaches are able to reduce the amount of failed requests significantly compared to common benchmarks from literature.

Braunschweig, Germany
January 2019

Jan Brinkmann

Contents

Acronyms

ADP	Approximate Dynamic Programming
AV	Autonomous Vehicle
BSS	Bike Sharing System
DLA	Dynamic Lookahead Policy
DPS	Dynamic Policy Selection
IRP	Inventory Routing Problem
LA	Lookahead Policy
LUT	Lookup Table
MDP	Markov Decision Process
PTS	Public Transport System
SMS	Shared Mobility System
SLA	Static Lookahead Policy
STR	Safety Buffer-tending Relocation Policy
VFA	Value Function Approximation
VRP	Vehicle Routing Problem

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Chapter 1
Introduction

Increasing urbanization and mobility demand lead to a large volume of traffic in urban areas. As the traffic infrastructure is limited, too much traffic results in traffic jams, noise, and air pollution. City administrations focus on a reduction of the individual traffic to tackle these discomforts. Therefore, collective traffic modes, i.e., public transport systems (PTSs), are launched or expanded. Conventional modes are buses and trams. On the one hand side, PTSs may be able to reduce urban traffic. But on the other hand side, the comfort is reduced. First, the users' actual origins and destinations are not necessarily in walking distance to a bus or tram station. Second, buses and trams are often delayed or crowded.

Shared mobility services (SMSs), such as car, bike, and scooter sharing systems, are promising alternatives as well as complements to conventional PTS. An SMS grants the access to an available wheeler where the user does not become the owner. The access is granted for one trip, i.e., for the time span the user needs to drive from his origin to his destination. A trip can be started any time a car, bike, or scooter is available without restrictions due to timetables. When the user ends his trip, it becomes available to other users. In this way, car sharing systems can reduce the number of cars in the city significantly (Archer 2017). Further, bike sharing systems (BSSs) offer emission-free and sustainable transport. In free-floating BSSs, bikes are distributed in the operation area. In station-based BSSs, the access to bikes is granted at stations, i.e., bikes are rented and returned at predefined locations. Stations are capacitated, i.e., a limited number of bike racks is available. The network of stations expands over the city center as well as residential areas. Thus, users can satisfy there mobility demand completely with the BSS if origin and destination are in cycle distance. BSSs serve as a complement to PTS if the next PTS stations is not in walking distance. Then, a user can rent a bike near his origin and can cycle to the next PTS station (Lin and Yang 2011).

Information technology found its way into BSSs to support user authentications and payments, and to record rental and return requests (Vogel 2016). The resulting availability of data allows data analysis to reveal spatio-temporal patterns of requests. BSSs are often used by commuters. Accordingly, in the morning, commuters request to rent bikes in residential areas and request to return bikes in working areas. In

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