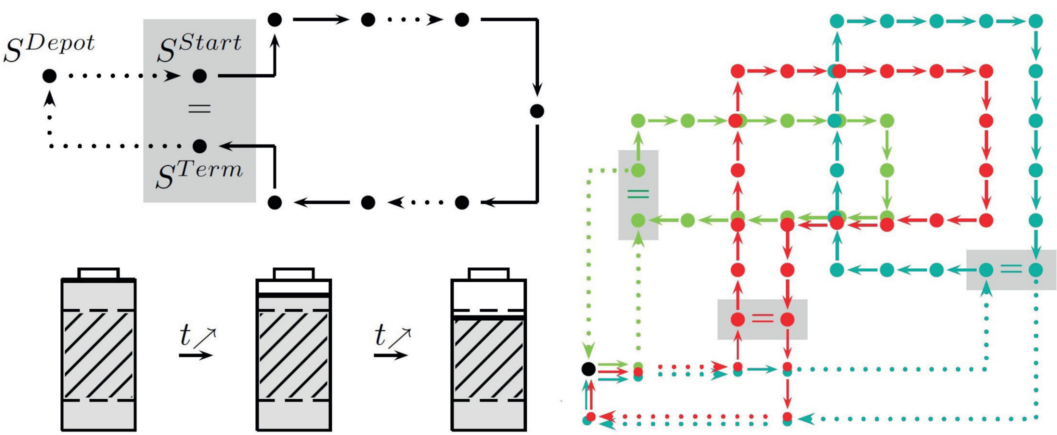
# Location Planning of Charging Stations for Electric City Buses

Brita Rohrbeck



# Location Planning of Charging Stations for Electric City Buses

Zur Erlangung des akademischen Grades eines
Doktors der Ingenieurwissenschaften
(Dr.-Ing.)

von der Fakultät für Wirtschaftswissenschaften
des Karlsruher Instituts für Technologie

angenommene

DISSERTATION

von

Dipl.-Math. Brita Rohrbeck

---

| | |
|---|---|
| Tag der mündlichen Prüfung: | 19. Februar 2018 |
| Referent: | Prof. Dr. Stefan Nickel |
| Korreferent: | Prof. Dr. Natalia Kliewer |

Karlsruhe, Januar 2018

Operations Research

**Brita Rohrbeck**

# Location Planning of Charging Stations for Electric City Buses

Shaker Verlag
Düren 2019

**Bibliographic information published by the Deutsche Nationalbibliothek**
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Karlsruhe, Karlsruher Institut für Technologie, Diss., 2018



Printed in Germany.

ISBN 978-3-8440-6654-8
ISSN 1862-6327

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

# Acknowledgements

This work is about being on the road. It is characterised and driven by travelling, sometimes detours or changing direction. Every slow-down on rough terrain was followed by new speed, though—often even increased thanks to the support of my supervisor and colleagues, my friends and family.

I am grateful for all motivation and suggestions, for every question and doubt, for all the help and succour. Every challenge also gave me the opportunity to grow and gain new experience. I appreciate the trust and the great latitude I was always allowed as well as the flexibility and the funding that enabled me to broaden my horizon, to discover new areas and to gain new insights.

Thanks to everybody who encouraged and supported or sometimes just distracted me. Thanks to everybody who simply joined my journey with a smile.

# Abstract

Modern urban transportation concepts increasingly involve the usage of electric vehicles, in particular of electric city buses. Many projects on electric private transport are already undertaken, and a lot of investigation is done with respect to advantageously located charging stations for the individual traffic. Examinations on the electrification of bus networks are rare, though.

In the city of Mannheim, Germany, the bus line 63 has recently been electrified. Customers are now served with contactless charging buses. Along the route of line 63, charging stations are installed. This enables the vehicles to recharge their batteries during the usual service, when halting at bus stops or during breaks at termini. The solution that has been implemented in Mannheim was determined on the basis of experiences and estimations of the local transport services *Rhein-Neckar-Verkehr*. Models from the area of operations research were not applied. This fact suggests to assume potential for improvement of the implemented solution. The realised configuration of line 63 in Mannheim shall therefore serve as a reference in this work. The aim is to develop a model, based on the conditions of line 63, to validate the model with real-world data and to enhance it for further investigation.

In this work, a basic mixed-integer linear model is presented in order to determine a cost-optimal distribution of charging stations for one bus line. This model is reformulated in favour of smaller computational times. Both, the initial and the reduced model, are enhanced by different features: The possibility of various types of batteries is

integrated, different charging technologies may be employed, and the option of an additional bus is given.

Subsequently, the approach is extended from just one bus line towards a network of lines. Again, two formulations are given, evaluated and also compared with respect to their run times.

Battery ageing has a crucial influence on the feasibility of a solution also in the succeeding years. As a consequence, a multi-period model is introduced and complemented with a battery ageing function. To the initial and a reduced formulation of this more complex problem, valid inequalities are added and examined with respect to their effectiveness.

The models are applied to data sets, which are based on real-world data of the bus network of Mannheim. They are solved with Cplex. Various scenarios are drawn to assess the implications and the sensitivity of a solution. The base scenario corresponds to line 63. By means of this reference line, the quality of the solutions is verified. For the basic scenario, the determined solution involves one additional charging station. Accordingly, it has higher costs than the solution implemented in Mannheim. However, the realisation in Mannheim turned out to be not feasible. The calculated solution hence excels the applied one. This fact proves the quality of the calculated solution and in turn the validity of the presented models.

# Contents