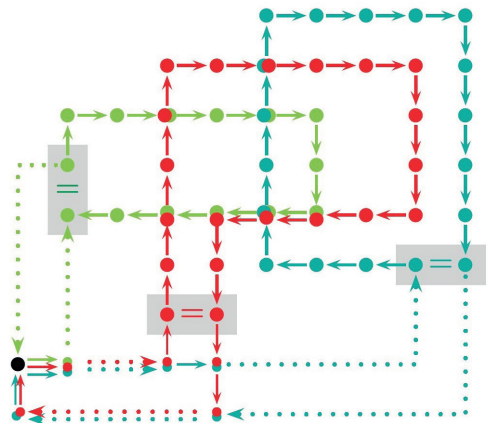
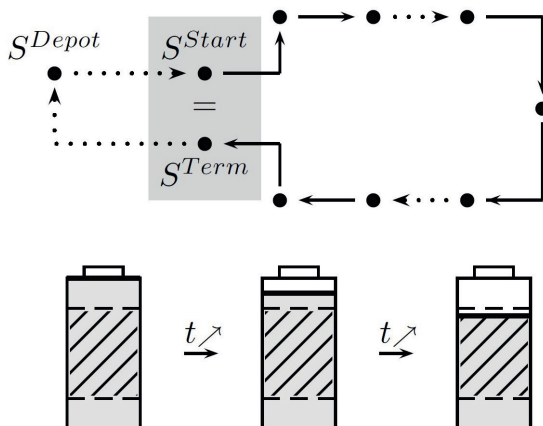


Location Planning of Charging Stations for Electric City Buses

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

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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

List of Abbreviations	ix
List of Figures	xvii
List of Tables	xxi
List of Algorithms	xxiii
1 Electric Urban Bus Networks—State of the Art	1
1.1 Motivation for Electric Urban Bus Networks	2
1.2 Different Concepts of Electric Urban Bus Networks . . .	5
1.3 Battery Ageing	7
1.4 E-Bus Projects	9
1.4.1 E-Bus Projects in Germany	9
1.4.2 <i>emil</i> and PRIMOVE Mannheim	12
1.4.3 E-Bus Projects in Europe and Worldwide	14
1.5 Further Literature	16
2 Underlying Data	23
2.1 Description of the Project PRIMOVE Mannheim	24
2.1.1 Rhein-Neckar-Verkehr GmbH	26
2.1.2 Bus Line 63 of <i>rnv</i> in Mannheim	27
2.1.3 Characteristics of the Bombardier PRIMOVE Buses	29
2.1.4 Characteristics of the Bombardier PRIMOVE Charging Stations	30

2.2	Parameters Derived from PRIMOVE Mannheim and Line 63	32
2.2.1	Energy Consumption	34
2.2.2	Energy Supply	38
2.2.3	Fixed Costs	40
2.2.4	Synergies in Usage of Charging Stations	42
2.2.5	Constructional Restrictions and Further Stopping Options	42

3 Location Configuration for One Electric City Bus Line **45**

3.1	Modelling the <i>Charging Stations Location Problem</i> for One Bus Line	46
3.1.1	Sets of Indices	46
3.1.2	Decision Variables	48
3.1.3	Parameters	49
3.1.4	Model: <i>Charging Stations Location Problem</i>	51
3.2	Reducing the Model	55
3.3	Extending the <i>CSLP</i> by Different Technology Options	57
3.3.1	Incorporating Different Battery Types	58
3.3.2	Incorporating Different Charging Technologies	59
3.3.3	Model: <i>CSLP with Different Technology Options</i>	60
3.4	Additional E-Bus vs. Dense Charging Infrastructure	63
3.4.1	Decision Variables, Parameters and Modification	63
3.4.2	Model: <i>CSLP with an Optional Auxiliary Bus</i>	66
3.5	Realisation in Mannheim	70
3.6	Computational Tests	74
3.6.1	Basic Scenario with Average Values	77
3.6.2	Sensitivity to a Temporary Failure of a Charging Station	81
3.6.3	Minor Change in Timetables	83
3.6.4	Worst Case Scenario	85
3.6.5	Possibility of an Auxiliary Bus	87
3.6.6	Current Technologies	90
3.6.7	Future Technologies	93
3.6.8	Run Times	95

4	Network Configuration for Electric City Buses	99
4.1	Modelling the <i>Charging Stations Location Problem for a Network</i>	100
4.1.1	Sets of Indices	101
4.1.2	Decision Variables	105
4.1.3	Parameters	105
4.1.4	Model: <i>Charging Stations Location Problem for a Network</i>	106
4.2	Reducing the Model	111
4.3	Extending the <i>CSLPN</i> by Different Technology Options	112
4.4	Computational Tests	117
4.4.1	Data Derivation	117
4.4.2	Network Configuration with Current Technologies	123
4.4.3	Network Configuration with Future Technologies	125
4.4.4	Run Times	127
5	Incorporating Battery Ageing	129
5.1	Necessity to Consider Battery Ageing in the <i>CSLP</i>	131
5.2	Modelling the <i>CSLP with Battery Ageing</i>	136
5.2.1	Decision Variables	136
5.2.2	Parameters	138
5.2.3	Model: <i>Charging Stations Location Problem with Battery Ageing</i>	138
5.3	Reducing the Model	146
5.4	Auxiliary Decision Variables and Valid Inequalities	153
5.4.1	Auxiliary Decision Variables	153
5.4.2	Valid Inequalities	155
5.5	Computational Tests	156
5.5.1	Basic Scenario with Average Values and Realistic Ageing Factor	157
5.5.2	Basic Scenario with Average Values and Optimistic Ageing Factor	159
5.5.3	Basic Scenario with Average Values and Two Pessimistic Ageing Factors	159
5.5.4	Run Times	160

6 Conclusion	165
6.1 Summary	165
6.2 Limitations	167
6.3 Outlook	168
Appendix	171
A Input and Output	171
A.1 Input Basic Model Scenario 1	171
A.2 Output Basic Model Scenario 1	175
A.3 Additional Input for Multi-Period Models	178
B Background Material on PRIMOVE Mannheim	181
B.1 Collected Data	181
B.2 rnv	185
Bibliography	197