

Optimization of Electric Car Sharing Stations: Profit Maximization with Partial Demand Satisfaction

Bachelorarbeit

zur Erlangung des akademischen Grades „Bachelor of Science (B.Sc.)“
im Studiengang Wirtschaftsingenieur
der Fakultät für Elektrotechnik und Informatik, Fakultät für Maschinenbau und der
Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover

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Hannover, den 17.06.2015

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1 Introduction

1.1 Motivation

“Cities in mature countries with a high proportion of motorized individual transport need to fundamentally redesign their mobility systems so that they become more consumer and sustainability orientated.“ (Lerner, 2011)

This statement points out two motivational aspects of the inevitable reformation of today’s mobility systems: ecological and economical sustainability in times of an increasing shortage of fossil-based resources, rising energy costs and global warming, and the growing consumers’ awareness of environmental responsibility.

Given the finite nature of fossil energy sources, the world faces major challenges in the continuity of power supply on fossil-based resources while the energy consumption is still increasing. It is disputable, whether or not peak oil has arrived; some analysts argue that the maximum rate of global petroleum extraction is reached, which drives up prices for oil and natural gas (Deffeyes, 2008; Duncan & Youngquist, 1999). However, it is undeniable that substituting energy sources (e.g. solar and wind energy, fuel cells and fermentation gas) need to be located and evolved not only to meet the demand and ensure secure energy supply, but also for the sake of the environment. In order to avoid the most harmful impacts of climate change, the Intergovernmental Panel on Climate Change calls for a reduction of greenhouse gas emissions in developed countries by 25% to 40% by 2020 and 80% to 95% by 2050 (European Commission, 2012a). A large part of this reduction can be made in the field of transport. Thereby, electric vehicles (EVs) show great promise for a sustainable, climate and environmentally friendly future mobility. They are becoming more and more efficient and thus important for emission reduction and independence from fossil fuels (Nationale Plattform Elektromobilität (NPE), 2014).

With an increasing percentage of the world living in cities, the reduction of CO₂ emissions is crucial, especially in densely populated areas. 3.5 billion people, 51% of the world population, lived in urban areas in 2011 with an expected progression to 70% by 2050. Almost two-thirds of all traveled kilometers are made within these urban areas, and the amount of travel is expected to triple by 2050 (Lerner, 2011). In Germany, the population is expected to decline in size, yet the number of cars held in private ownership will continue to rise according to a scenario by Ritter & Vance (2013). In order to improve the quality of life in urban areas, car sharing provides an efficient alternative to public transport and other means that help cut back the private car ownership ratio, deal with the scarcity of parking capacities and general lack of space on streets, reduce air pollution and congestion and keep the cities clean.

As a result of the growing eco-consciousness of today's society and the sensitivity to the individual carbon footprint, consumers are more attracted to innovative sustainable mobility concepts like car sharing. Already more than 3.5 million users are assigned to car sharing organizations worldwide with numbers growing continuously, encouraged by governmental promotion initiatives such as the German Schaufenster Elektromobilität (Briggs, 2014; Nationale Plattform Elektromobilität (NPE), 2014; Shaheen & Cohen, 2013). Additional to a lower rate of car ownership, car sharing can also contribute to the implementation of electric vehicles, as they are currently too cost-intensive for the private market. The advantages of electric mobility can thus be combined with the benefits of car sharing in the "Electric Car Sharing" approach.

The challenge of this implementation consists in the sizing and allocation of an electric car sharing fleet and the corresponding charging infrastructure, which are crucial factors for the attractiveness of car sharing systems and thus for the profitability of car sharing organizations. Despite the extensive research on both, car sharing and electro mobility, little literature exists on the decision support for the implementation of electric car sharing stations. The present thesis thus seeks to develop an algebraic model for the optimization of electric car sharing stations.

1.2 Objective

In the course of this thesis, an optimization model is developed, implemented and evaluated, which shall maximize the profit of an electric car sharing organization (CSO) by computing size and positioning of the car sharing fleet and stations. The derivation and formulation of the model bases upon existing work by Sonneberg (2014) with significant enhancements and improvements: A relaxation of the full demand satisfaction constraint precludes the opening of unprofitable stations and thus optimizes the allocation of car sharing stations for profit maximization. The following central research question can be derived from the objective of this thesis:

*Can the profit of electric car sharing organizations be optimized
with partial demand satisfaction?*

1.3 Course of Investigation

Following the introduction, chapter 2 gives the theoretical background of the two basic technology concepts discussed in this thesis, outlines research methods and introduces existing work on electric car sharing station optimization. After a declaration of the system characteristics and assumptions, chapter 3 then presents the mathematical formulation and the computerized implementation of the proposed optimization model. The model data, market

demand for car sharing in the major German city of Hanover, and parameters are presented in chapter 4 and the model is verified via sensitivity analyses using benchmarks. This is followed by a discussion of the outcome and limitations of the optimization model with recommendations for further investigations. Finally, the results of this thesis are summarized in chapter 6 and this paper is concluded with a brief outlook on future research.

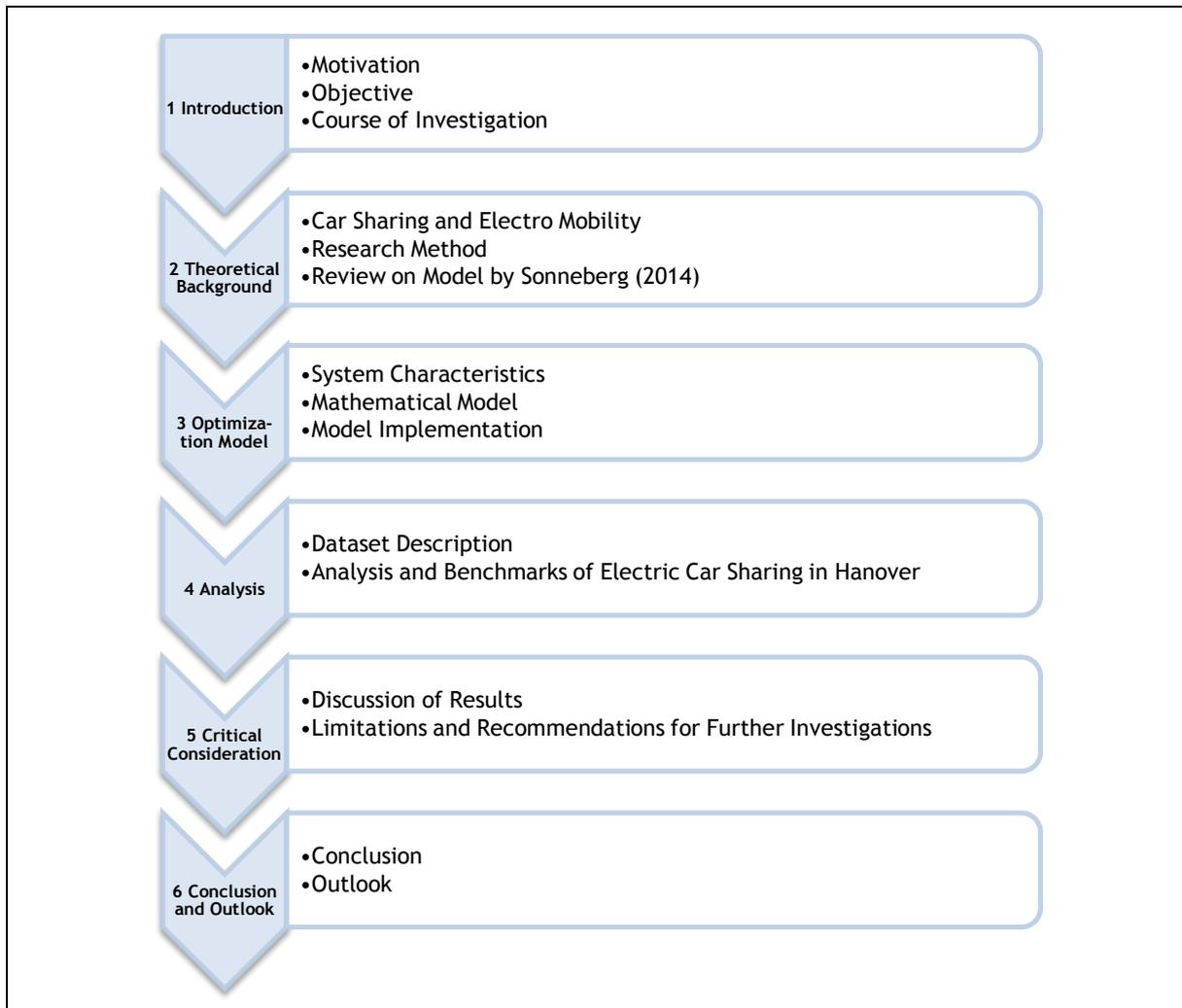


Figure 1: Course of Investigation

6 Conclusion and Outlook

In times of climate change, declining fossil energy resources and a growing urban population, the concept of electric car sharing offers a promising approach for sustainable transportation. Thereby, the allocation of stations and shared vehicles is the key factor for the profitability of a car sharing organization.

In the course of this thesis, an existing optimization model was adopted and enhanced to optimize the allocation and size of car sharing stations with partial demand satisfaction. Subsequent to the formulation and implementation of the model, an evaluation was conducted using the example of Hanover, a major German city, and its applicability and feasibility were assessed and demonstrated. However, certain limitations were identified. In particular, a better transferability of the OR-based model could be achieved by empirical studies investigating car sharing usage and demand criteria. The possibility to satisfy a certain fraction of the demand at different demand points and assign that demand to more than one station could also contribute to a more accurate representation of the real world situation. Very good results with a gap of two percent or less can be computed within few minutes. This provides the car sharing organization with a means for strategic planning, where particularly the variation of parameters, e.g. different charging cycles, can be analyzed in order to find the optimal solution.

To conclude, it can be said that electric car sharing shows the potential to contribute to sustainable mobility and a better quality of life. The proposed optimization model thereby provides decision support for the strategic planning of electric car sharing. Regarding this very complex task, this model should be further amended in order to allow for a sustainable implementation of electric car sharing in both, economic and ecological, dimensions.