Optimization of Electric Car Sharing Stations: Mathematical Formulation and Decision Support System

Masterarbeit

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1 Introduction

1.1 Motivation

Growing levels of eco-consciousness in both, public and business sectors, combined with an increasing percentage of the world living in cities, evokes a rethinking of car usage and personal vehicle ownership.[1] Factors such as rising energy and ownership costs, sensitivity to environmental sustainability, and growing importance of corporate social responsibility cause people to employ transportation alternatives.[2] Besides other means of public transport, the concept of car sharing has thus become a mainstream way of travelling, with more than one million users worldwide and the number is growing exponentially.[3] Car sharing enables users, who do not own a car, to satisfy their mobility needs by paying trip-dependent fees. Thereby, the sustainability effect increases with the number of people using this concept. To reach the largest amount of potential users possible, the challenging task of positioning and sizing car sharing stations is a critical success factor.

With an end to cheap oil towards the years 2030 to 2040 and tightening emission standards, an additional important sustainability aspect is the type of car engine. Electric vehicles are becoming more and more efficient and provide for vast local emission reduction, which can especially help areas with a high population density to become cleaner. The energy efficiency of a fuel-powered vehicle driven in a city falls below 15 percent. With 80 percent of all vehicles driven in cities, 42.5 liters of a 50 liter fuel tank are thus transformed into heat and pollutants.[4] This emphasizes the need for alternative means of transport, but also shows the tremendous potential of electro-mobility. However, electro-mobility is not yet meeting the cost-value ratio for a private market. Therefore, the concept of offering electrical car sharing vehicles is one approach to profitably install electric mobility in an urban environment and thus combine the positive aspects of car sharing with the advantages of electric vehicles.

An approach to meet the challenge of combining the car sharing allocation problem with electric vehicles are green information systems (IS). Green IS contributes to sustainability by utilization of adequate design and implementation of information systems.[5] The application of

[1] See Dedrick (2010), p. 174 and Shaheen and Cohen (2013), p. 5.

[2] See Shaheen and Cohen (2013), p. 5 and Dedrick (2010), p. 174.

[3] See Shaheen and Cohen (2013), p. 5f and Frost and Sullivan Ltd (2013).

[4] See Van Mierlo and Maggetto (2007), p. 166.

[5] See Boudreau, Chen, and Huber (2009), p. 2.

green IS through an interaction of information technology (IT) and people enables the optimization of processes and products to raise resource efficiency and therefore helps to achieve direct and indirect conservation of resources, as well as higher sustainability. Even though car sharing is an essential concept to increase sustainability of individual mobility, existing literature gives little methodological support for car sharing in the context of green IS, so far.

The motivation of this thesis can consequently be summarized with the help of a citation by El Fassi, Awasthi, and Viviani (2012): "Currently, the decision makers rely on an intuitive strategy selection process which often results in inadequate decisions being made representing an immediate loss in resources, time and market penetration."[6] This thesis makes a contribution on the way to change this.

1.2 Objective

Based on existing work on decision support for planning stations and operation research (OR) models, this thesis introduces an optimization model and a decision support system (DSS) for the positioning and sizing of car sharing stations.

The concrete aim is the development, implementation, and test application of an optimization model that takes into account electric vehicles in a two-way car sharing mode and a time-dependent demand. It shall thereby compute the optimal network of stations and vehicles and maximize the profit of the car sharing organization (CSO). The mathematical optimization model shall then be implemented into a DSS with a clear graphical user interface (GUI) to provide for easy and self-explanatory settings and adjustments during usage. In detail, the GUI shall help the user to import, edit, export, and visualize data, to set parameters, trigger numerical solving of the underlying model, and visualize optimization results. Several constraints, based on corresponding adjustable parameters, shall be elaborated in addition to the objective function. These shall comply with the objective function and are supposed to ensure feasible and realistic results to enhance the value of the model. The application of the model shall then verify the profitability of electric car sharing, with Hanover and Zurich as application examples. After review and adjustment of the corresponding datasets for both cities, benchmarks shall explain the influences of the different parameters and also substantiate the applicability of the model/DSS.

[6] See El Fassi, Awasthi, and Viviani (2012), p. 6692.

This leads to the following research questions:

1. How can the DSS and the underlying model from Rickenberg, Gebhardt, and Breitner (2013) be amended and expanded to allow for the allocation of electric car sharing stations, taking into consideration the effects of peaks and off-peaks while maximizing the profit?
2. Can the concept of electric car sharing be profitably realized?

1.3 Course of Investigation

As an orientation, this chapter explains the structure of the thesis, which is divided into seven chapters. Adjacent to the introduction, the theoretical background regarding car sharing, electromobility, and the applied methodology, is explained. Chapter 3 is then dedicated to the model; it first gives an overview on literature closely linked to car sharing models, then describes the model of Rickenberg, Gebhardt, and Breitner (2013), and finally introduces the newly developed model. Subsequently the decision support system "OptECarShare 1.5" is elaborated in chapter 4. The following chapter 5 applies the model and gives an overview on the corresponding benchmarks. The thesis is then critically reviewed in chapter 6, while chapter 7 concludes the work with a short summary and an outlook. To ease the overview, the following figure summarizes the structure of the thesis.

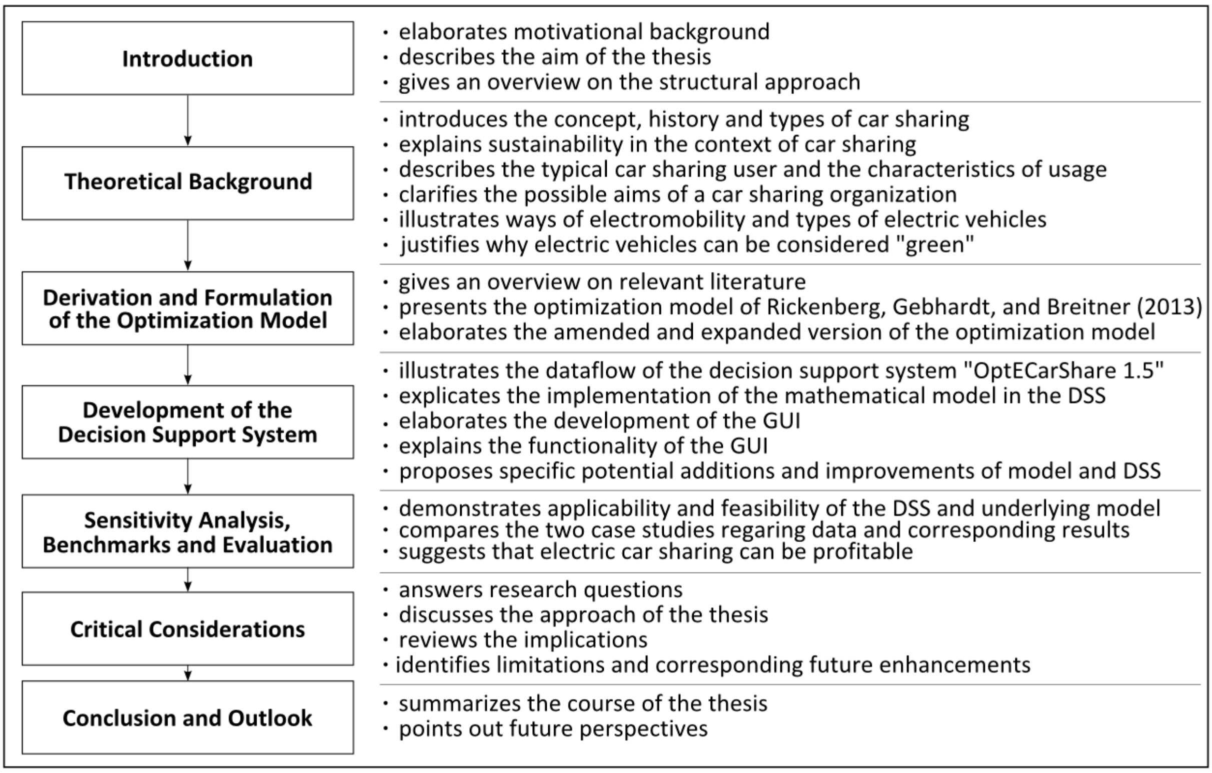

Figure 1: Outline of the Master Thesis

7 Conclusion and Outlook

In the course of this thesis, an existing model was amended and expanded to provide decision support for the complex task of planning the optimal locations and sizes of electric car sharing stations. The integration of the model into an improved DSS enhances the applicability and usability of this approach. The DSS provides a user-friendly interface, allows data import, review, and adjustment, as well as parameter setting; it further triggers the optimization and visualization of results. Applicability and feasibility of the DSS and the underlying model were evaluated and demonstrated by the example of the major cities Hanover and Zurich. For better comparability between the cities, the case study of Hanover therefore was extended by a second dataset with 100 additional potential stations and 20 additional demand points. The close relationship between the green IS approach in this thesis and artifacts of electric car sharing was explained, as well as its possible contributions to environmental sustainability.

While the applicability and usefulness of the optimization model and the DSS were assessed and shown, certain limitations were identified. Considerable benefits could be drawn from deeper empirical evaluation in the field and a more profound quantitative analysis, which is suggested to be carried out in the context of the DSR relevance cycle. The ongoing cooperation with a German car sharing company shall foster this suggestion and also take future amendments and unconsidered requirements into account.

Especially with regards to the model, implications for additional research can be derived. The optimization model itself can and should be refined further by the scientific community to achieve constantly increasing sustainability through green DSS. The most promising topic in this regard is a further customization of the demand, which could help to draw a clearer picture and ensure better transferability during the realization phase of the OR process. Among others, this includes a relaxation of the requirement to completely satisfy the demand as well as the possibility to assign a demand to more than one station.

In conclusion, it can be emphasized that the potential of electric car sharing is considerable, with regards to both, sustainability as well as profitable installation. The developed model thereby supports the strategic planning phase by providing decision support. Along with further enhancements, this thesis can contribute to support society’s way towards a low emission and noise-reduced environment.