A Tactical Optimization Model for Car Sharing Networks with Heterogeneous Vehicles

Masterarbeit

zur Erlangung des akademischen Grades „Master of Science (M.Sc.)“ im Studiengang Wirtschaftswissenschaft der Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover

vorgelegt von

Name: Bromann

Vorname: Kira

[redacted]

[redacted]

[redacted]

Prüfer: Prof. Dr. Michael H. Breitner

Hannover, den 30.09.2015

Contents

1 Introduction

1.1 Motivation

Limited natural resources, an increasing level of eco-consciousness of society and a constantly increasing demand for individual mobility at the same time are emphasized in today's world.[1] In addition, almost half of the world's population is living in cities and the urbanization still continues. According to estimates it is expected that approximately 60% of the world's population is living in cities in the year 2030.[2] Besides these factors, economic uncertainty, rising energy costs and the wish to reduce greenhouse gas emissions are reasons why the means of transportation are questioned. In this context, the usage of vehicles is reconsidered and new mobility concepts and alternatives to vehicle ownership are sought.[3]

Such an alternative urban mobility concept is carsharing. Carsharing means that individuals gain access to a fleet of shared-use vehicles in a network of locations instead of owning a private vehicle and pay for it on an as-needed basis.[4] Thus, "individuals gain the benefits of private vehicle use without the costs and responsibilities of ownership".[5] Due to technological progress, the mobility market is developing faster than ever before. This is also valid for carsharing which became more and more popular in the last decade and is one of the current major trends. Especially the modern information and communication technologies contribute to a growing success of carsharing. The availability, location and status of each vehicle can be checked online and by using mobile applications this information has become accessible any time and any place. Hence, carsharing operations were simplified to a large extent in recent years and today a high service level can be offered to the customers.[6] Due to these circumstances, the number of people using carsharing

[1]See Briest and Raupach (2011), p. 167.
[2]See Shaheen and Cohen (2013), p. 5.
[3]See Shaheen and Cohen (2013), p. 5.
[4]See Shaheen, Cohen and Roberts (2005), p. 2.
[5]Shaheen, Cohen and Roberts (2005), p. 2.
[6]See Hayashi, Hidaka and Teshima (2014), p. 274 - 279 and Kaspi, Raviv and Tzur (2014), p. 36.

is rising rapidly all over the world. In Germany, for example, the number of carsharing members rose from approximately 270,000 to more than one million in the last three years.[7]

Carsharing operations can reduce negative impacts of vehicle usage, such as energy consumption, emissions, congestion and inefficient land use.[8] Especially the effects of reduced emissions and reduced energy consumption from limited resources can be reinforced by including vehicles with an alternative propulsion system in the carsharing fleet.[9] Therefore, several carsharing operators have already commited to reduce the emissions of their fleets voluntarily. With vehicles that have a low fuel consumption and low emissions, in many cases hybrid vehicles, they meet requirements of different environmental labeling programs which are mostly voluntary.[10]

To satisfy as much demand for carsharing trips as possible and to benefit from the advantages of vehicles with an alternative propulsion system simultaneously, the task of planning the optimal fleet size and fleet composition is a critical success factor for a carsharing operator. During the planning process the advantages of such vehicles have to be contrasted with the higher costs and practical difficulties (such as the installation of a charging infrastructure).[11]

1.2 Objective and Research Questions

The objective of this master thesis is the development, formulation and application of an optimization model for a carsharing network with heterogeneous vehicles considering a tactical planning horizon. According to Günther and Tempelmeier (2005), the tactical planning or management shall contribute to achieve the aims set by the strategic management. While the strategic planning is in charge of establishing the framework conditions on a long-term basis, the tactical planning refers to a period of middle duration. In contrast, there also exists the operational management which has the function to make use of the potentials created by the decisions of the tactical planning and is based on a short-term basis.[12] Concerning the optimization of a carsharing network the following decisions are part of the different planning levels.

[7] See Bundesverband CarSharing e.V. (2015a).
[8] See Shaheen and Cohen (2008), p. 81.
[9] See Diez and Kohler (2010), p. 11.
[10] See Millard-Ball et al. (2005), p. ES-4 and 2-4.
[11] See Millard-Ball et al. (2005), p. 2-24.
[12] See Günther and Tempelmeier (2005), p. 26 - 27.

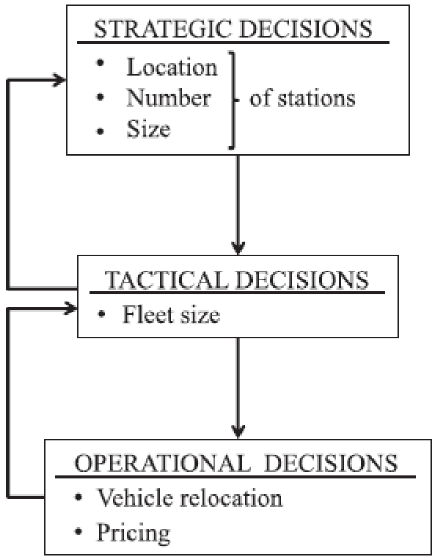

Figure 1: Strategic, tactical and operational decisions that have to be done by a carsharing operator, based on Boyaci, Zografos and Geroliminis (2015), p. 721.

The strategic planning process includes the decisions about the optimal location, number and size of the carsharing stations. If these stations are established, a decision about the fleet size has to be done, followed by the pricing and vehicle relocation (which is only necessary if the network consists of an one-way carsharing system). As can be seen, the decisions of the different planning levels cannot be handled separately in a strict manner. Each decision influences another and is linked to the previous and subsequent planning. Hence, an interaction between these three levels takes place. Since this thesis deals with the tactical planning horizon, a basic scenario is assumed which comprises the results of the strategic planning. That is, the location, number and maximum size of the stations was already determined in advance. Thus, the concrete aim is to develop an optimization model for a two-way (or round trip) carsharing system with heterogeneous vehicles and a time-dependent demand that determines the optimal fleet size and fleet composition. Existing work on decision support for carsharing systems and operation research models constitute the basis for this. Since the objective function of an operation research model can pursue different objectives, in consideration of particular constraints, two models will be developed in the course of this work. The first model pursues the objective of minimizing the total costs occuring for a carsharing operator and the second model maximizes the net profit for this operator. The following research questions can be drawn from that:

- *Which factors of a heterogeneous fleet influence a tactical optimization model?*
- *How can a tactical optimization model for carsharing networks with heterogeneous vehicles be developed and formulated?*
- *What influence has a change of different parameters on the decision variables and results?*

At this point, a short guideline for this master thesis is provided by giving an overview of the structure. The thesis is divided into eight chapters. Subsequent to the introduction, the theoretical foundations and background regarding carsharing, its types, history, objectives and benefits are explained. Furthermore, the existing literature dealing with the subject of carsharing optimization is reviewed and the research gap concerning the topic of this thesis is worked out. In chapter 3, factors that influence a tactical optimization model for a carsharing network with heterogeneous vehicles are identified. Different vehicle propulsion systems and different vehicle classes are presented and their influence on a tactical planning of a carsharing network is highlighted. In the following course of this thesis two mathematical optimization models are developed which are introduced and explained in chapter 4. In the following chapter 5, the new models are applied by executing several benchmarks based on the city of Hanover. The results are used in chapter 6 to formulate predications that are generally valid. In chapter 7, this thesis is critically reviewed and limitations are pointed out. The work is concluded by giving a short summary and an outlook on future research.

8 Conclusion and Outlook

The focus of this thesis was the development, formulation and application of a tactical optimization model for carsharing networks with heterogeneous vehicles. Since the objective function of an operations research model can pursue different objectives, two models were developed to determine the optimal fleet size and fleet composition. The first model aimed at minimizing the total costs occuring for a carsharing operator and the second model maximized the net profit for this operator. The applicability of both models was demonstrated in chapter 5 by executing several benchmarks in the course of a sensitivity analysis by the example of the major city Hanover. In chapter 6, generalizations of the results were worked out and presented in detail. Since a formal model cannot represent the reality completely and without some mistakes, certain limitations of both models were identified in the previous chapter.

An advantage of these developed models is their universality. That is, the applicability is not limited. Due to the introduction of indices, the amount of vehicle classes and types as well as the amount of established stations, demand locations and time frames can be chosen individually. For example, it is quite possible to integrate additional vehicle types, such as plug-in-hybrid vehicles, and additional vehicle classes, such as the class of medium or mini cars. Moreover, the models can be applied for any city in the world which satisfies the described conditions of a successful implementation of carsharing. This fact should be used in future tests by applying the models in other and bigger cities to ensure futher generalizations.

Regarding the fleet composition, it has been determined that the heterogeneity of the fleet must not be too high to be cost-efficient. This was proven by the fact that the fleet composition never consists of all possible combinations of vehicle classes and types. Since hybrid vehicles emit less emissions than vehicles with an interal combustion engine, have lower leasing costs than electric vehicles and do not require a charging process, they constitute a suitable middle solution and, thus, are always the most included vehicle type.

Furthermore, several recommendations and possible enhancements for future work were provided. Future research could improve the developed models by taking into account the described limitations. Since the knowledge of the demand is a key factor for a successful implementation and since most of the limitations face the problem of modeling and handling the time-dependent demand in a still more appropriate way, this problem should be paid particular attention in future research. In addition, the expected duration and distance driven of a trip have to be investigated in greater depth. Empirical studies could help to cope with this challenge. Especially the aspect of the applicability of the models for an one-way carsharing system should also be considered in the future because it is a fast growing concept with a high future potential.

In conclusion, it can be emphasized that the two optimization models of this thesis close a gap in the existing literature. By providing two different approaches, the tactical management can be supported in its decision making process. Nevertheless, it has to be pointed out that the decisions of the different planning levels influence each other and are linked to the previous and subsequent planning level. Thus, every planning level must not be handled separately. The interaction between the strategic, tactical and operational management was also taken into account in this thesis by considering results of the strategic planning (location, number and maximum size of the stations) and by giving incentives for the operational planning (basic concept for the charging system).