Masterarbeit

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Development of a Car-Sharing Simulator Including Electric Vehicles

Jan Isermann, B.Sc.
Geboren am 02.12.1988 in Großburgwedel

Prof. Dr. Michael H. Breitner
Wirtschaftswissenschaftliche Fakultät
Institut für Wirtschaftsinformatik

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Contents

1 Introduction

In the last century, the worldwide population has increased steadily and is about to reach an astounding 8.5 billion people in 2030. Since individuals strive for both material security and a certain level of wealth, the need for basic as well as consumption goods is expected to consistently rise. However, as this additional demand can only be satisfied by a boosting production leading to higher emissions of green house gases, thus promoting global warmth, both the public and private sectors are inclined to search viable and innovative solutions to manage the growingly scarce resources while simultaneously decreasing the level of green house gases.

One of these solutions can be found in the concept of car sharing. Car sharing, in short, allows one to temporarily rent and therefore gain access to vehicles which they could use to perform daily tasks (cf. Stillwater et al. 2008, p. 1). By joining a car sharing service, the users gain the mobility and flexibility of having a car at their disposal, while also avoiding the responsibilities and costs resulting from regular insurance fees and maintenance costs or the initial purchase (cf. Shaheen and Cohen 2013, p. 5; Markel 2010). Consequently, sharing a vehicle not only offers economic advantages but also indicated positive environmental impacts, such as for traffic-related issues. Hence, a decrease in the overall number of privately owned vehicles helps to reduce congestion or the lack of parking spaces (cf. Shaheen and Cohen 2013, p. 7; Lee et al. 2012, p. 89; Parent and Gallais 2002, p. 827).

Moreover, since global warming has become more and more an issue, individuals are developing an environmental consciousness and starting to actively think about their role in the process of climate change. As car sharing offers a possibility to both reduce financial costs and one's carbon footprint, car sharing has become more and more popular as an alternative means of transportation. This development is also reflected in the numbers of active car sharing members. Since its first appearance in 1965, where usually only a handful of people shared a small pool of cars, car sharing programs have grown impressively. Nowadays 1.25 million persons regularly use car sharing services and the fleet-size has almost doubled in the last fifteen years to 31,000 vehicles in 2010 (cf. Shaheen and Cohen 2013, p. 7).

Although alternative means of transportation are becoming more and more popular, worldwide greenhouse gas emissions, fuel and energy costs still continue growing, thus promoting and intensifying the search for further means of optimization (cf. Alli et al. 2012, p. 1; Barth et al. 2003, p. 2; Figueiredo et al. 2001, p. 1206). Being one of these solutions, car sharing companies have deployed electric vehicles worldwide in order to test their applicability and economic viability in real environments (cf. Shaheen and Cohen 2013, p. 9; Alli et al. 2012, p. 1).

However, due to very expensive field testing for car sharing systems, other methods have been developed by researchers allowing for the evaluation of the performance of car sharing system prior to their implementation. One of these methods is found in the field of simulation. Simulation tools offer possibilities to simulate the consequences of planning decisions and initial assumptions of decision-makers on the overall system performance by creating multiple scenarios depicting the potential future. Thus, decision-makers can explore various car sharing concepts accruing trade-offs through different scenarios, thereby improving the overall understanding of the system and interactions therein (cf. Farina 2013, p. 3).

Although simulations are a viable and common method in the domain of car sharing, none have ever been applied in the field of electric car sharing. Despite this significant lack of research, researchers have mostly confined themselves to analyzing, describing and predicting user behavior in casual car sharing systems, subsequently creating a research gap (cf. Jorge et al. 2012, p. 205). In order to fill this gap, this paper proposes a car sharing simulator that incorporates electric vehicles and their pecularities while also simulating the entirety of the car sharing process, consisting of system, user, station, and vehicle-inherent processes. It is intendec to serve as a decision support tool supporting decision-makers, researchers, and other users given its convenient application, simplicity, customization opportunities.

After the introduction and the description of the purpose and value of this paper in the first section, section two deals both with explaining the fundamentals of simulations, as well as presenting and categorizing various simulations in the domain of car sharing. Whereas in subsection 2.1 components of simulation such as models and systems are introduced, the second subsection 2.2 will consist of a small literature review of previous simulation approaches to car sharing. The concept of the proposed car sharing simulator is presented in the third section. In the first subsection of the respective section, the various general features the simulator is supposed to encompass are derived by a visualization of the underlying car sharing process. Furthermore, certain design decisions made by the author are explained. Subsection 3.2 introduces the specific concept of the car sharing simulator in detail, including the description of the various entities of the simulation system and their interactions in the general process. In section 4, the code of the various simulation classes, which are the entities of the system, is presented and explained in detail. In the fifth and second to last section, the actual simulation will be conducted. For that purpose, a variety of scenarios are introduced and possible simulation outcomes are described in subsection 5.1. In subsection 5.2, the actual scenario analyses are conducted, whereas the interpretation of the results follows in subsection 5.3. A critical reflection and discussion of the respective simulation results is performed in section 6. Possible limitations will be identified and matched to either system-related issues or process-related issues, where the former are described in subsection 6.1 and the latter in subsection 6.2. Section 7, being the last of the paper, provides a final conclusion of the various sections and results of the paper.

2 Simulation & Car Sharing

In order to gain a better understanding of the meaning and purpose of simulations and its possible applications in the domain of car sharing, the following chapter starts by giving a comprehensive overview of the various components researchers have to decide upon when thinking about setting up simulations. Moreover, basic terms will be explained briefly and the various common simulation models will be categorized and introduced.

After this initial examination, a brief literature review concerning the application of simulations in car sharing will be conducted. In this consecutive subsection, some of the respective studies will be introduced and filed according to their domain of application, namely demand, relocation, and performance simulations. However, as these studies resemble each other process-wise, solely a selection of studies will be introduced in detail in each domain. Anyone who is further interested, can consult table 1 which contain additional studies.

2.1 Systems, Models, and Simulation

Over the last decades, simulations have become the most popular tool in the domain of operations research being most commonly applied in the area of manufacturing (cf. Law and McComas 1999, p. 56; Kelton and Sadowski 2010, p. 3). In general, the term simulation "...refers to a broad selection of methods and applications to mimic the behavior of real systems..." and its environment (Kelton and Sadowski 2010, p. 3). More specifically, simulations can be regarded as the "...process of designing and creating a computerized model of a real or proposed system for the purpose of conducting numerical experiments to give us a better understanding of the behavior of that system for a given set of conditions..."(Kelton and Sadowski 2010, p. 7).

Therefore, simulating **systems**, which can briefly be defined as a set of interacting entities, components, or elements that follow certain predefined rules, enable researchers and decision-makers alike to test their performance and consequently allow for their optimization before they are actually implemented (cf. Backlund 2000, p. 448; Hachicha et al. 2010, p. 2). In particular, simulations are used to determine the need for and the quantity of equipment and personnel. Therefore, they help during the initial set-up or to evaluate operational procedures and the overall performance of the systems to be, thus being a viable tool for their continuous improvement (cf. Law and McComas 1999,

7 Conclusion

Due to the continuous research and subsequent improvements of battery technology and a general decline in the acquisition cost of electric vehicles, the latter's popularity has been shown to grow steadily. Besides a general increase in private use, electric vehicles have become more and more popular in the domain of car sharing. Despite this increasing popularity, researchers have almost exclusively confined their studies either on field tests of already existing e-Car sharing systems, or on simulating car sharing services using common vehicles. In order to fill this research gap, the aim of this paper consisted of developing a car sharing simulator including electric vehicles and their peculiarities, thus allowing researchers or other users alike to preemptively test for the viability of e-Car sharing systems by conducting various scenario analyses.

To provide the reader with a convenient access to the topic, the thesis began with describing the diverse basics in the domain of simulation. The various types of simulation models were categorized and simulation systems and their components were explained. Subsequently, a literature review of simulations in the domain of car sharing was conducted. It was found that most of the respective simulations focus on certain fractions of the car sharing process and none of them included electric vehicles in their observations. After finding and describing this research gap, the concept for the e-Car sharing simulator was developed. For that purpose, a car sharing process was visualized, according to which the features of the simulator were derived. Furthermore, as a simulation system is always a simplified depiction of reality, simplifying assumptions, including omitting of reservations and one-way-rentals, were made. Afterwards, these general features and the interactions therein were translated into a specific concept that included a description of all entities, their properties, and their part in the simulation.

In the following section, the specific implementation, that is the translation into code, was explained in great detail. The simulator consists of the four classes *Simulator*, *Vehicle*, *Station*, and *Customer*. Whereas the last three classes play a passive role in the simulation, the simulator class defines the behavior of the simulation system, since it encompasses the actual simulation process.

In order to test for the applicability of the e-Car sharing simulator, multiple scenarios were defined and distinguished. Furthermore, expected tendencies and respective outcomes of these scenarios were suggested, in order to check whether the actual simulation results meet these expectations, and thus, if the simulation behaves as intended. Afterwards, the simulation of the scenarios was conducted and the results were presented. Subsequently, the results were interpreted and recommendations for car sharing operators were derived. It was found that both the number and the type of the charging stations play a significant role for the success of the e-Car sharing companies, as they have a critical influence on the average charge and thus, on the vehicle availability. The vehicle availability, in turn, has been found to notably influence the profitability of the car sharing service, because it directly impacts the number of successful rentals, which in turn are responsible for generating revenue. However, it was also found that these impacts are comparably small as long as the car sharing service is quite new and the frequency of rentals is low. In these cases, the intervals between each rental were mostly long enough that the vehicle had enough time to become sufficiently charged for the next trip. Moreover, it has been found that the demographic structure of a city district also plays an important role for the success of car sharing systems, as different customer structures require different vehicle distributions due to their vehicle preferences. Thus, car sharing services are required to ensure that the distribution of vehicle types matches the customer distribution and their preferences. In addition, the number of stations was found to be a critical success factor as well. The car sharing companies are required to reflect on the optimal number of stations. On the one hand, they are expensive to build but on the other hand, having not enough stations leads to a significant decrease in active customers, as the customers will not walk greater distance to rent vehicles.

Finally, the results of the simulation were reflected critically, because both during the design of the simulation and its translation into code, simplifying assumptions were made by the author. These are expected to hamper the validity of the results, since they lead to either an over- or underestimation of certain key performance indicators. For instance, ommiting a reservation feature was discussed. It was expected to significantly increase the waiting times, since currently, customers will go to their next station and, if no vehicle is available, will wait until either they waited too long, or a suitable vehicle arrives.

However, one of the biggest issues of the proposed simulator is the significant lack of scientifically backed input data. Therefore, the current customer behavior is more or less based on assumptions, as car sharing operators and researchers alike are very secretive when it comes to customer data and especially driving behavior such as number of rentals and length of stay. Furthermore, the validity of the simulation could not be confirmed by comparing it with other simulators, because no similar systems and e-Car sharing simulators exist.

As a consequence, future users, be it researchers or car sharing operators, are inclined to find out the actual usage and customer driving patterns, thus allowing for an appropriate customization and calibration of the current simulator. Doing so would increase its applicability and reliability, consequently allowing users to use it both for supporting their decision-making regarding either existing or conceptual car sharing systems.