Travel Behaviour and Society xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Implementation of free-floating and station-based carsharing in an agent-based travel demand model

Michael Heilig *, Nicolai Mallig, Ole Schröder, Martin Kagerbauer, Peter Vortisch

Institute for Transport Studies, Karlsruhe Institute of Technology (KIT), Kaiserstrasse 12, 76131 Karlsruhe, Germany

ARTICLE INFO

Article history:
Received 9 June 2016
Received in revised form 12 December 2016
Accepted 14 February 2017
Available online xxxx

Keywords:
Carsharing
Travel demand model
Agent-based model

ABSTRACT

The number of carsharing cars and users is growing throughout the world. Although there is a comparatively small share in modal split, carsharing is becoming more important as a supplemental transport mode, especially in metropolitan areas. This implies a need to further develop planning tools, so that this "new mode" can be considered in the planning process. This paper illustrates the integration of carsharing in an agent-based travel demand model that simulates the travel behavior of the population in the greater Stuttgart area for one week. Since it is the first time that carsharing usage is simulated for more than one day, this model permits longitudinal analysis of the intensity and variability of carsharing usage.

1. Introduction

Carsharing as a mode of transport is gaining in importance. Particularly in metropolitan areas, carsharing is a growing market and represents a non-negligible part of urban mobility. In Germany, the number of carsharing users and the number of cars offered in sharing systems has increased throughout the last years, and forecasts show that this is an ongoing trend. Within the past year, for example, station-based carsharing had an increase in customers of 60,000 (+18.8%), while free-floating carsharing had an increase in customers of 223,000 (+51.0%) (Bundesverband CarSharing e.V, 2015). Clearly, the "new" transport mode carsharing has become a component of many people's daily travel routines.

In general, commercial carsharing is classified into two systems: station-based and free-floating. Station-based carsharing is the traditional system in Germany. In this system, the cars are located at fixed stations, and customers go to the stations to pick up their cars. Afterwards, the cars have to be returned to the same stations. Customers need to reserve their cars in advance. Station-based carsharing providers usually offer different types of cars, such as compacts, station wagons and vans. Free-floating systems operate without stations. Instead, the cars are distributed within a defined service area. Customers check the availability and location of cars online via computer or smartphone. In free-floating systems, reservations are not required. At the end of a ride, customers can park their cars wherever they want within the service area. Free-floating carsharing providers typically offer just one type of car.

The dramatic success of free-floating carsharing during the last years has been significantly driven by car manufacturers, who have also invested in upcoming mobility-service companies, such as moovel (Car-2-Go by Daimler) or Drive-Now (BMW), in order to offer flexible transport mode options to trip makers and promote their carsharing services. These mobility-service companies also provide multimodal and intermodal information about trips with all modes to improve customers' mobility planning.

The growing usage of carsharing cars (Bundesverband CarSharing e.V, 2015) and thus the changing travel behavior (Katsev et al., 2001), especially in large cities, implies a need to further develop planning tools, so that this "new mode" can be considered in the planning process. In this paper, we describe how we integrate carsharing in the agent-based travel demand model mobiTopp (Mallig et al., 2013), which simulates travel behavior over a period of one week. To our knowledge, this is the first time carsharing usage has been simulated with a transport planning tool for more than one day, which therefore allows for longitudinal analysis. However, since no data was available for estimating valid model parameters, we did not use the model for forecasting yet.

This paper is a revised version of a paper presented at the 94th TRB Annual Meeting (Heilig et al., 2015) and is structured as follows: First, we briefly introduce the related work. Second, we describe the agent-based model mobiTopp. Third, we discuss the implementation of the customer model, the modifications of the mode choice model and the calibration processes. Finally, we show the results and end with a short conclusion.

* Corresponding author.
E-mail addresses: m.heilig@kit.edu (M. Heilig), nicolai.mallig@kit.edu (N. Mallig), ole.schroeder@kit.edu (O. Schröder), martin.kagerbauer@kit.edu (M. Kagerbauer), peter.vortisch@kit.edu (P. Vortisch).

http://dx.doi.org/10.1016/j.tbs.2017.02.002
2214-367X/

2. Literature analysis

Since we model carsharing customers and their usage of carsharing services in a microscopic travel demand model, our analysis of existing work focuses on two topics – estimating the number and the travel demand of carsharing customers.

Research on carsharing customers is often related to studies on the potential growth of carsharing. The main assertion is that the demand for and the number of carsharing systems is growing throughout the world. After the first commercial introduction in the late 1980s in Switzerland, station-based carsharing services arose in Germany (Nobis, 2006) and in North America (Shaheen et al., 2009) at the beginning of the 1990s, followed by Japan and Singapore (Barth et al., 2006) at the beginning of the millennium. After the first free-floating system was introduced in Ulm, Germany, in 2008, this innovative and more flexible form spread into the market and made carsharing more attractive.

Within the last few years, Germany has recorded yearly growth rates in carsharing members of more than ten percent. Currently (in the year 2015), 1.04 million people are carsharing customers of more than one hundred operators in Germany (7). Several studies on carsharing potential focus on the yearly car-mileage of users. Petersen (1995) and Prettenthaler and Steininger (1999) determine a break-even-point of yearly car-mileage, below which people are willing to switch from owning a car to sharing a car. Schuster et al. (2005) developed an economic model that describes costs as central to the decision of owning or sharing a car and applied it to the city of Baltimore, USA. Nobis (2006) estimated the potential for carsharing customers at about 6% of licensed drivers living in cities with more than 20,000 inhabitants in Germany, considering both socio-demographic criteria and current travel behavior.

Despite increasing membership and utilization rates, research in modeling carsharing is still in its early stages. Rodier and Shaheen (2003) were probably the first to attempt to estimate the demand for carsharing. However, the representation of carsharing in the mode choice of their four-step demand model was very basic: Stations were located at transit hubs and employment centers only, and the use of vehicles was restricted to direct links between these hubs. This resulted in a high level of vehicle availability, but a low level of flexibility. Since every agent was able to use carsharing, a customer model was not implemented. The mode choice of travelers was mainly based on travel time and costs.

In recent literature, the MATSIM community has incorporated carsharing in a microscopic agent-based model. Ciari et al. (2009) discuss several reasons why agent-based simulation is a good tool to model carsharing: An agent-based model is not only suitable for modeling rational choices, it is also suitable for describing the environmental framework at high resolution. Ciari et al. (2011) describe how the existing microscopic travel demand model MATSim was adapted to incorporate carsharing. Initially, they employ a station-based carsharing system with a simple approach (no membership requirement, unlimited availability of cars, and no cost considerations) using the existing car driver's utility function for carsharing and applying it to the simulation area of greater Zurich. Their results show that the approach works, but needs further extensions to produce reliable results.

Ciari and Weis (2013) were probably the first to take an agent-based approach to model the choice of becoming a customer of a carsharing provider, considering personal socio-demographic attributes and the access to shared cars by using a binary logit model. Ciari et al. (2014) enhanced the MATSIM framework, also by combining the aforementioned extensions: both, station-based and free-floating systems, are modeled, the capacities of the system are taken into account, carsharing vehicles are physically simulated, and specific components, such as time and cost for access, egress and rental time of carsharing travel are defined. With this model, which is applied to the Berlin area, it is possible to analyze comprehensive information on travel demand in geographical as well as in behavioral matters over the course of one day. This model has also recently been applied to the Zurich area (Balac et al., 2015).

The analysis revealed that carsharing is a hot topic becoming more and more important for people's everyday mobility, especially in urban areas. However, our analysis also shows that research in the field of microscopic travel demand Modeling is still at its beginning. In contrast to the existing approaches considering only the travel demand of an average workday, our microscopic simulation models the carsharing usage during one week. Hence, by implementing carsharing in our model framework *mobiTopp*, we are able to analyze the intensity and variability of carsharing usage from a longitudinal perspective.

3. The Agent-based simulation mobiTopp

mobiTopp (Kagerbauer et al., 2015; Mallig et al., 2013) is a travel demand model based on the principle of agent-based simulation (Bonabeau, 2002). In this model, each person in the planning area is represented as a separate entity, a so-called agent. Each agent has an activity schedule, consisting of activities of different types (e.g., home, work, education, leisure, shopping), which are executed during the simulation period of one week. Within the simulation process, each agent decides where to execute each activity and which mode to use to get to the chosen destination. Each agent is modeled in the context of its household. Cars are owned by households, not by individual agents, so that the actual car availability for an agent in a multi-person household depends on the behavior of the other household members. The temporal resolution of the simulation is one minute; the spatial resolution is based on zones.mobiTopp consists of two parts: a long-term and a short-term model. In the long-term model, facts that are stable over a longer period are simulated, for example, population, car ownership, or long-term pass ownership for public transport. In the short-term model, destination choice and mode choice are simulated for all agents in a chronological manner.

The essential step in the long-term model is the population synthesis. It is based on the socio-demographic data of persons and households on a zonal level and using a household travel survey. For each household in the survey, a weight is calculated by an iterative fitting procedure. It is similar to the approach used by Müller and Axhausen (2011) to adjust the survey data to the zonal statistics. The population is generated by randomly drawing the adequate number of households from the weighted survey data. For each household drawn from the survey, a corresponding simulation household is created that inherits the attributes (e.g., household size, number of cars owned) from the survey household. For each person in the survey household, an agent is created that inherits the attributes (e.g., age, sex, employment) and the activity schedule (only sequence of activities with start times and durations for each day) of the survey person. In the next step, fixed locations for work and education activities are assigned, since the locations for these types of activities usually don't change during a week. The location for home activities is already determined by the zone for which the household was created. Ownership of long-term passes for public transport is determined using a binary logit model.

In the short-term model, the travel behavior of all agents is simulated simultaneously and chronologically based on their individual activity schedules. When an agent finishes an activity, it looks for the next activity in activity schedule. The agent chooses a loca-