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Modeling the impact of parking price policy on free-floating carsharing: Case study for Zurich, Switzerland☆

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ABSTRACT

The research on carsharing has already shown that a non-negligible part of carsharing members give up a vehicle after joining a carsharing program, or avoid a vehicle purchase. This arguably reduces overall parking space needed. This might well be one of the most important impacts of a carsharing program on the transportation system, but also one of the least researched. The rapid diffusion of free-floating carsharing, which for its very nature might have a stronger impact on parking, makes the relationship between carsharing and parking an appealing topic for new research. This work presents a method for the investigation of this relationship using an agent-based simulation and explores the impacts of different parking prices on the demand for free-floating carsharing in the city of Zurich, Switzerland. Three levels of free-floating fleet-size in the city of Zurich coupled with three levels of parking prices were simulated. The obtained results show that free-floating vehicles are able to use parking spaces more efficiently than private vehicles. Moreover, the average parking occupancy tends to be more homogeneous with higher fleet-size of free-floating carsharing and with the increase of parking prices, thus avoiding spatial parking pressure peaks.

1. Introduction

Several studies have found that a non-negligible part of carsharing members give up a vehicle after joining a carsharing program, or avoid a vehicle purchase (Millard-Ball et al., 2005; Becker et al., 2016). This arguably reduces overall parking space needs. This might well be one of the most important impacts of a carsharing program on the transportation system, but also one of the least researched. The studies on the relationship between carsharing and parking are indeed sparse (Millard-Ball et al., 2006; Shaheen et al., 2010). The rapid diffusion of free-floating carsharing, which for its very nature might have a stronger impact on parking, makes this relationship an appealing topic for new research.

Traditional, round-trip based carsharing has an impact on parking exclusively through the reduction of the number of vehicles in the system. With such a scheme the vehicle remains reserved for the whole duration of a round-trip. This implies that the vehicle needs to be parked while the user is performing an activity at a given location, like with a private car. With free-floating carsharing, however, the vehicle is generally booked for a single trip only. As soon as the destination is reached, the vehicle is parked, the rental ends and the vehicle becomes available for the next user. Potentially, this allows a more efficient vehicle's use, increasing the time the vehicle is traveling and reducing the time the vehicle is occupying a parking slot. This would mean a larger positive impact on parking than that of traditional carsharing. Moreover, the increased efficiency, could help avoiding

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parking-pressure peaks. A higher turnaround of parking spaces might increase the ease of finding an empty parking space, therefore increasing the satisfiability of people.

The work presented in this paper aims at producing knowledge which can support, or oppose, the hypothesized mechanism for the city of Zurich. A methodology to model carsharing operations is developed and is implemented as a pluggable module inside of the open-source, Java based, multi-agent transport simulation framework (MATSim, www.matsim.org). The methodological aspects of using MATSim for carsharing simulations has been presented by Ciari et al. (2009) and since then, the carsharing module in various stages of development, has been used in several studies (Ciari et al., 2014; Ciari et al., 2015; Balac et al., 2015; Balac et al., 2016). It was shown before, that the simulation using the carsharing module is capable of generating plausible predictions of carsharing usage according to given characteristics of the service. A pluggable MATSim module modeling parking choice behavior, has also been developed in the past few years (Waraich et al., 2013). The current paper presents a framework that integrates carsharing and parking modules and is flexible and easily pluggable into MATSim. It features newly developed, flexible and pluggable carsharing framework. The proposed methodology is used to evaluate impacts of parking price policies on free-floating carsharing usage and parking in general. This demonstration shows how the tool will help designing effective policies for easing parking pressure in an urban area.

2. Background

2.1. Carsharing and parking in Zurich

The first implementation of carsharing in Switzerland date back to the 1948 (Harms and Truffer, 1998). Currently, in Switzerland, there is a nationwide round-trip carsharing service provided by Mobility (Mobility, 2016) whereas Catch-a-Car (Catch-a-Car, 2016) a subsidiary of Mobility, provides free-floating carsharing in the city of Basel since 2014 and at the time of writing this paper about to start operations in Geneva. Round-trip carsharing, besides having dedicated parking slots at stations, requires parking spaces at the locations where the individuals perform their activities. Therefore, it can be said that round-trip carsharing vehicles require the same amount of parking space as privately owned ones.

At the moment, the city of Zurich offers approximately 50,000 curb parking spaces, 16,000 spaces in parking garages and over 200,000 private parking spaces (Tiefbau- und Entsorgungsdepartement der Stadt Zürich, 2016). Parking spaces on the streets are part of the blue- or white zone. In the blue zone they are free of charge, but there is generally a park time limit of one to two hours (except on Sundays and public holidays). Spaces in the white zone are managed with parking meters. Residents also have the possibility to obtain a parking permit for 300 CHF (1 CHF = 1.04 USD on 15.06.2016) per year that allows them to park inside the blue zone in the district of the city where they live, without a time limit. Prices in parking garages on a workday vary from 0.5 to 4.40 CHF per hour depending on the location. There is also a guidance system, in a form of traffic signs, that helps drivers to find parking garages with empty spaces (Stadt Zürich, 2016).

Zurich also has a peculiarity in terms of parking policy, as back in 1996, a regulation was introduced that limits the amount of parking space in the center of Zurich to the level of 1990. This, coupled with increasing number of vehicles over the last decades increased the parking pressure in the city.

To decrease parking pressure, a free-floating carsharing service might be a viable solution. Moreover, the increasing popularity of free-floating carsharing worldwide and its recent introduction in Basel and Geneva, suggest that it might be launched soon in Zurich and that gives us a solid base to place the current study in the Zurich area.

2.2. Carsharing simulation models

Carsharing is a service with limited supply and unpredictable availability. Therefore, its modeling requires detailed representation on both spatial and temporal dimensions. In the last decade there were increasing number of proposed methods to model and observe the impacts of carsharing. A paper by Jorge and Correia (Jorge and Correia, 2013) provides a review on methods to model carsharing. However, the paper is clearly outdated in the meantime, as the field evolved very quickly and several methodological innovations were introduced in the last few years (Balac et al., 2016). Among several agent-based simulations proposed to model carsharing, most of them usually lack some of the following important aspects: a learning process of agents, demand being sensitive to supply, demand depending on dynamic interaction among agents, high level of spatial and temporal resolution. All these processes are implemented in MATSim and are explained in the following sections.

2.3. Parking simulation models

Work done by Hess and Polak (2004) suggests that there is a substantial variance in individual preferences when different aspects of parking are considered, like search time, parking costs, walking time etc. Parking supply, on the other hand, also influences other aspects of the daily schedule, like location, route or mode choice. Therefore, it is very important to have a tool that can take into account all these aspects and their interactions. In this sense, agent-based models seem appropriate, as individual preferences are taken into account and agents have the possibility to adapt their schedule to a given situation. To the best knowledge of the authors only a small number of agent-based simulation models for parking exist, which can take individual preferences into account (Benenson et al., 2008; Dieussaert et al., 2009) and only the one proposed by Waraich and Axhausen (2012), based on MATSim, is able to represent the rescheduling behavior of agents (and therefore the change in demand) based on the change of the parking supply (availability, costs, etc.).

3. Modeling approach

The work presented in this paper has been carried out using the already mentioned agent-based transport simulation framework, called MATSim (Horni et al., 2016). The software, through the agent paradigm ((Kelemen, 2004)) simulates daily life of individuals.

Each agent in MATSim has a daily plan of trips and activities, such as going to work, school or shopping. The initial daily plans of agents are provided in the initial demand together with supply models, e.g. street network and building facilities. The plans of all agents are executed by a micro-simulation, resulting in traffic flows along network links, which can cause traffic congestion. The coupling of demand and supply in an iterative process is what makes the learning of the agents possible. The simulation iterates between plan generation and traffic simulation. In each iteration a portion of the agents is allowed to improve their plans by modifying one of their plans. Most of the agents prefer plans with a high score, while sometimes they are allowed to re-use plans with an inferior score. Each agent keeps a limited number of plans in its memory, from which he makes a choice. Choice set generation and traffic simulation is explained in more detail below.

3.1. Choice set generation

Each agent in the initial state has in its memory one plan. The plan contains an ordered list of activities and connecting trips during the course of the day. The plan explains in detail the type, location and duration of activities as well as transportation modes, routes and expected departure or travel time. The maximum number of plans (the choice set) that each agent can keep in his memory during the simulation can be predefined. During the course of the simulation each agent constantly updates its choice set by modifying his plan. Available modifications used in this case study are:

- **Route choice:** An agent is allowed to change the routes of its trips in order to find a better route.
- **Time allocation:** An agent can move its departure times from the activities in order to avoid congestion or to increase the performing time of some of its activities.
- **Mode change:** An agent changes its mode, choosing from one of the modes available to it.

Each of this modification strategies have 10% chance of being executed in each iteration. If none of these strategies is selected an existing plan from agent's memory is chosen and executed. In this way, a fast and stable convergence of the simulation is achieved during the iterative process. After certain number of iterations, choice set generation is turned off, allowing the agents to choose from the stable choice set using the utility-based choice model described below.

3.2. Plan choice and utility function

In order to evaluate how a plan performs and to provide a mechanism for comparing different plans a quantitative score is assigned to each plan.

The score of the plan is computed using the utility function that evaluates each component of the agents daily plan (Eq. (1)).

$$U_{plan} = \sum_{i=1}^{m} (U_{act,i} + U_{travel,i} + U_{parking,i}) \tag{1}$$

where m is the number of activities that agent has in his daily plan. In general, performing activities increases the score (positive utility), while traveling decreases it (negative utility).

A multinomial logit model is used to model the plan choice and thus the probability that a plan will be selected is as follows:

$$P_i = \begin{cases} 1 & \textit{if } i \textit{ is newly generated plan} \\ \sim \exp(\mu \cdot U_{plan}) & \textit{otherwise} \end{cases} \tag{2}$$

where μ is controlling the preference for higher scores and in this work it was set to $\mu = 1$

If in search for more detailed read about the choice selection one is advised to look in Horni et al. (2016) and specifically in Flötteröd and Kickhöfer (2016).

What follows is the description of the different parts of the utility function and specifically scoring of carsharing and parking is explained.

The utility of an activity is defined as:

$$U_{act,i} = U_{dur,i} + U_{wait,i} + U_{late.ar,i} + U_{early.dp,i} + U_{short.dur,i} \quad (3)$$

$U_{dur,i}$ is the central part of the activity scoring and represents the utility of performing the activity, where the opening times of activity locations are taken into account. A logarithmic form is used to calculate the utility of performing:

$$U_{dur,i} = \beta_{perf,i} \cdot t_{typ,i} \cdot \ln(t_{perf,i}) \quad (4)$$

where $t_{typ,i}$ is the typical duration of the activity, $t_{perf,i}$ is actual performed duration and $\beta_{perf,i}$ is the marginal utility of activity i at the typical duration. These typical durations are sampled from the empirical distributions that are extracted from the census data.

$U_{wait,i}$ is the utility (negative) for waiting (i.e. waiting for a store to be open) and $U_{late.ar,i}$ represents the utility (negative) of being late at an activity which is supposed to start not later than a certain time (for example going to school) and $U_{early.dp,i}$ represent leaving early from an activity which is supposed to last at least until a certain time (i.e. leaving the workplace before the shift is over). $U_{short.dur,i}$ is the penalty for performing the activity shorter than what is supposed to be a reasonable time for a certain activity (i.e. less than 8 h of work). All of these utilities have a linear form.

The specific components of free-floating carsharing travel are:

- Carsharing constant;
- Rental time fee;
- In-vehicle travel time;
- Distance cost.

The utility of traveling, using free-floating carsharing, between activities $i-1$ and i therefore looks as follows:

$$U_{travel,cs} = \alpha_{cs} + \beta_{cost,cs} \cdot Cost_t \cdot RT + \beta_{tt,cs} \cdot TT + \beta_{cost,cs} \cdot Cost_d \cdot Dist \quad (5)$$

$\beta_{cost,cs} Cost_t$ represents the utility of the time-dependent part of the rental fare, $\beta_{tt,cs}$ presents the utility of traveling while the distance-dependent part of the fare is captured with $\beta_{cost,cs} Cost_d$. Constant α_{cs} captures travel attributes not represented by other components.

Eq. (6) presents the utility of traveling (negative) for all other modes:

$$U_{travel,mode} = \alpha_{cs} + \beta_{tt,mode} \cdot TT + \beta_{cost,mode} \cdot Cost_d \cdot Dist \quad (6)$$

Parking utility (negative) is composed of the utility of access/egress walking times to/from the parking space and the parking cost (Eq. (7)) (for more details look at Waraich and Axhausen (2012)).

$$U_{parking} = U_{parkingCost} + U_{parkingWalk} \quad (7)$$

The parking cost part of the utility is then represented with the following equation:

$$U_{parkingCost} = \beta_{parkingCost} \cdot price \quad (8)$$

where $\beta_{parkingCost}$ is a parameter dependent on the income of the specific agent and price is the monetary fee for the parking duration (in CHF).

Walking utility is represented in a similar way (Eq. (9)).

$$U_{parkingWalk} = \beta_{parkingWalk} \cdot traveltime \quad (9)$$

where $\beta_{parkingWalk}$ is a parameter depending on activity duration, age and gender.

Both β parameters used here were adopted from the study on parking preferences in Switzerland by Weis et al. (2012)

3.3. Traffic simulation

The traffic simulation used in this study is QSim (Horni et al., 2016). QSim is a queue-based simulation, where traffic dynamics are modeled with waiting queues. This approach provides computationally efficient solution for large-scale scenarios. However, while this approach allows for the interaction of vehicles in a form of waiting queues at the intersections, it lacks car following or lane changing behavior.

4. Implementation of the carsharing-parking framework

In order to simulate carsharing services with high level of detail for both operator and user side which is flexible and easy to combine with other modules (in this case a parking module) we developed a new and pluggable carsharing framework. The high level architecture of this module can be seen in Fig. 1. Carsharing Framework consists of several submodules:

- **Carsharing manager:** Main communication unit between Carsharing and MATSim frameworks. It is responsible for providing vehicles to agents and maintaining the information about supply and demand. It also communicates with the Parking Module. It requests from the Parking Module a free parking location to park a carsharing vehicle. It also provides the information to the Parking Module when a carsharing vehicle is parked or when a parking slot becomes free.
- **Supply:** Information on all available carsharing operators, their services and price structures.
- **Membership:** Information on membership for all agents for each operator and each carsharing option.
- **Demand:** Information on all currently rented vehicles.
- **Models:** Models that provide certain information to the Carsharing Manager. This include, but is not limited to: should the agent keep the rented vehicle during its next activity or should it end its rental, from which operator should the agent rent a carsharing vehicle.

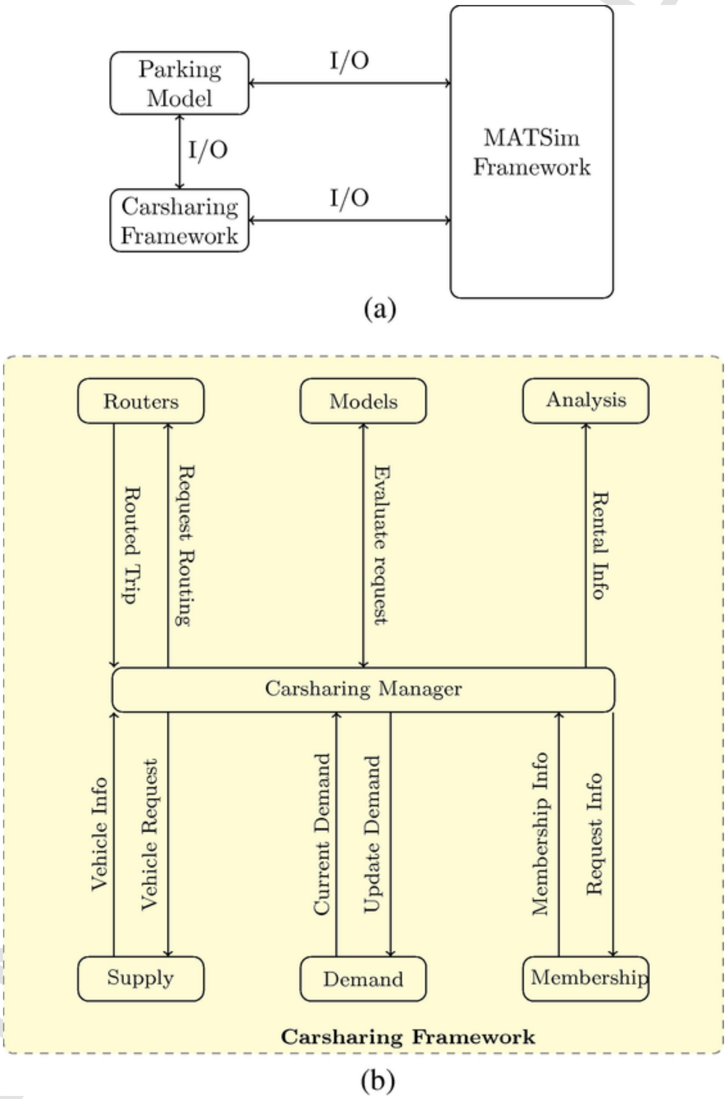


Fig. 1. High level architecture of the carsharing framework and its integration with the MATSim framework and parking module.

- **Routers:** Routes the current carsharing leg. Routers are flexible and can also create multimodal trips.
- **Analysis:** Stores information on all completed rentals and provides output information for later analysis.

Carsharing Framework is a flexible and easily pluggable module into the MATSim framework. It provides ability to have different carsharing operators, each providing different carsharing options and having different cost structures. Moreover, each agent can be a member of multiple programs.

4.1. Free-floating carsharing router

In this work we only used free-floating carsharing therefore only the free-floating router is explained in detail. The carsharing router, during the simulation, receives a request to route a carsharing trip. Along with the request, the router receives the following information:

- Agent whose leg needs to be routed.
- Vehicle that will be used.
- Location of the vehicle.
- Parking location at the end of the trip (obtained from the Parking Module).

The stages of the freefloating carsharing trips that the router sends back to the Carsharing Manager are as follows:

1. Access walk to the rented vehicle,
2. Carsharing Activity Interaction where the agent unlocks the vehicle and prepares for driving,
3. Vehicle trip that is routed on the network using the carsharing vehicle,
4. Carsharing Activity Interaction where the agent parks the vehicle and ends the rental,
5. Egress walk to the next activity

All these steps are subsequently simulated in the MATSim framework, meaning that the simulation of carsharing in MATSim does not require any structural change in the MATSim framework.

4.2. Membership

In the simulation only agents that have a carsharing membership are allowed to use carsharing. Membership is assigned based on the data obtained from a similar service operated by DriveNow in Munich, Germany. Members were drawn from the population of agents and fitted to the age and gender distributions observed in that data.

4.3. The parking choice model

Parking choice is defined as the decision of choosing a parking space from a set of parking spaces located in proximity of the agent's destination. The parking search process (cruising) is deliberately omitted in order to keep the model simple. Therefore, the model used in this study represents static decisions rather than on-the-fly decisions by an agent traveling along a link in a traffic simulation. The following parking types are part of the current parking model (Waraich and Axhausen, 2012):

- **Public parking:** Parking which is not reserved for anyone. All agents can compete for these parking spaces.
- **Private parking:** These parking spaces are assigned to specific activities and building (e.g. parking at home or at a shop, which can only be used by residents or shoppers)
- **Reserved parking:** Parking reserved for a selected set of agents. E.g. parking reserved for disabled people.
- **Preferred parking:** Sometimes a car must be parked at a location with a certain characteristics. E.g. a person driving an electric vehicle might require a parking space with a power outlet for charging.

The definition of the first three types depends on well-defined properties of a parking space while the fourth parking type also depends on individual preferences of the drivers and their current situation.

Parking module keeps track on all available parking spots and locations of already parked vehicles. It receives information from MATSim and Carsharing Frameworks on private as well as free-floating vehicles. It finds a suitable parking spot based on the agent's preferences and a type of vehicle (i.e. carsharing vehicles cannot be parked in garages).

5. Study area and calibration

This section presents in detail the study area and gives a short overview of the calibration process.

5.1. Study area

The study area represents a circle of 30 km radius, traced from a central place in the city of Zurich (Fig. 2). The agents modeled in the simulation are either residing in the area or are entering the area at some time during the day. Agents and their plans are a plausible representation of the population in the study area and their behavior based on census data and travel diaries. A high resolution navigation network, with approximately one million links, was used in the physical traffic simulation. The tests presented here, for computational reasons, use a 10% population sample, with around 160,000 agents. Network link flow capacities are adapted to match the population sample size in order to obtain realistic car travel times. The parking capacities and carsharing supply were also scaled accordingly. The choice dimensions for the agents, trying to optimize their daily plans, are mode, departure time, activity duration, route and parking location. The transportation modes available to the agents are car, free-floating carsharing, public transport, bike and walk, where only cars (including carsharing) were physically simulated along the roads. The travel times of the other modes were based on a simpler model - an average speed for bike, walk and public transport.

The free-floating carsharing service is limited to the city of Zurich. In other words, free- floating cars at the end of the rental could only be parked within this area. This limit was adopted in order to mimic the free-floating carsharing area size which we observe in practice. The free-floating rental fee was assumed 0.37 CHF/min as the one currently in use in Basel (Catch-a-Car, 2016).

Fig. 2. Study area (Carsharing service area is within the black polygon).

5.2. Calibration process

The scenario used was first calibrated without the parking choice module where an unlimited parking capacity is assumed at the destination activity and all the cars are parked at the destination location. The calibration of the scenario was done adjusting utility functions parameters in order to fit the output of the simulation to empirical data in terms of modal split and distance distributions whereas traffic counts data were used for validation (Rieser-Schüssler et al., 2016). In addition, the scenario was then re-calibrated using the parking choice module. As free-floating carsharing does not exist in the Zurich area, the β parameters in the utility function for carsharing were adopted based on the existing round-trip service as obtained in Balac et al. (2015) where the calibration and validation of the simulation of the round-trip service in MATSim was presented.

The calibration of the parking module can ideally be done using the occupancy counts for both on- and off-street parking spaces. Unfortunately, we do not have access to the on-street parking counts, therefore we used counts for the parking garages that we gathered using a web scraping technique from the website that displays the current parking occupancies. Therefore for the calibration of the parking module we have used 22 parking garages spread across the city and their occupancy was extracted at 20 s intervals. The comparison of the real and MATSim occupancy counts at these parking garages can be seen in Fig. 3. One of the reasons that we underestimate the occupancy of parking garages during the night hours is that in practice, certain number of these parking spots are rented on a monthly base which is at the moment not modeled in MATSim.

6. Results

As mentioned earlier we used a 10% scenario, but as a simplification the results presented in this section, are based on output data scaled up back to 100%.

To observe the implications of different parking prices on free-floating carsharing we assumed three levels of possible free-floating carsharing fleet size. Members are assigned according to age and gender and considering the members/vehicles ratio more or less constant:

- Low fleet-size: Carsharing fleet-size of 1300 cars available to around 60,000 members (46 members/vehicle).
- Medium fleet-size: Increased carsharing fleet-size with 5100 vehicles serving 220,000 members (43 members/vehicle).
- High fleet-size: Carsharing is available to 360,000 members that have 7650 vehicle at their disposal (47 members/vehicle).

The starting locations of free-floating vehicles for these three levels of fleet-size can be observed in Fig. 4. The initial distribution of vehicles covers the whole service area with higher density of vehicles in the city center. However, the old part of the city between the main train station and the lake (approximately in the center of the service area) has no vehicles because that area has limited parking space and it is mostly closed to traffic.

For each scenario we applied 3 parking fees: real current fees, 2 times higher fees and 4 times higher fees. The blue zone parking which takes around 70% of on-street parking supply remained to be free of charge.

The statistics for the nine scenarios have been summarized in Table 1. We observe the clear increase in the number of rentals, ranging up to 35% compared to the low fleet-size scenario with real parking prices, as the parking prices increase. The highest number of rentals as well as rentals per vehicle, is achieved in the scenario with the highest parking prices and large fleet-size. Moreover, increasing the fleet size and member pools accordingly the fleet utilization is improved (from 5.6 to 6.0 for medium

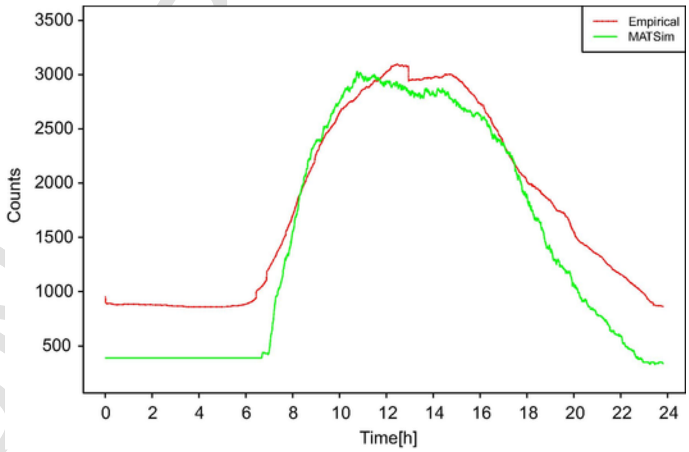


Fig. 3. Comparison of the garage parking counts.

Fig. 4. Starting locations of carsharing vehicles for a 10% scenario (a) low fleet-size scenario, (b) medium fleet-size scenario, (c) high fleet-size scenario.

fleet-size to 7.1 with high fleet-size). Even though this might look strange since the members/vehicle ratio is almost unchanged through these scenarios, it is clear when the fleet and service area size are considered. Larger fleet means also a better coverage and thus more effective utilization.

With the increase of parking prices both average access and egress distances drop. Higher parking prices, reduce the parking pressure from privately owned vehicles, creating higher parking availability. Therefore, free-floating cars could be parked closer to the destination, thus reducing the egress distance. Similarly, access distances also decreased, which might seem surprising because of the higher demand, but having in mind that some of the users who also use the free-floating vehicle for the return part of their tour, now have to walk less because previously they were able to park the free-floating vehicle closer to their activity.

Rental time of free-floating vehicles is shorter than the average trip duration by private car. This is expected, since carsharing service is limited to the area of the city of Zurich whereas the study area is much larger and private vehicles were used also for longer distance trips.

One of the most important outcomes of this study is that carsharing vehicles are used, on a trip level, between 1.7 and 2.9 times more than a private vehicle. In the calculation, we did not include private vehicles that were not used at all during the simulated day, which would increase this number even more. Moreover, taking into account the average rental length of a carsharing vehicle and average trip length with a private vehicle, we observe that on average free-floating vehicle is driven between 1.58 and 2.54 times more than a private one.

Rental start times are very similar among the different scenarios (Fig. 5). There is one smaller distinguishable peak in the morning and two higher peaks in the afternoon. On the other hand, the biggest change in the rental start times distribution is ob-

Table 1
Summary statistics for different scenarios.

Scenario	Low fleet-size			Medium fleet-size			High fleet-size		
Parking price	Normal	*2	*4	Normal	*2	*4	Normal	*2	*4
Rentals	7300	7970	9410	30,640	33,750	41,300	54,070	60,610	70,820
Rentals/per vehicle	5.6	6.1	7.2	6.0	6.6	8.1	7.1	7.9	9.2
Turnover [CHF]	19,320	20,080	23,820	79,300	85,480	103,650	143,920	155,510	181,290
Unique users	5560	6080	6880	22,690	24,590	29,660	40,160	44,500	50,680
Used ff cars	1230	1240	1240	4750	4840	4900	7350	7380	7500
Avg. rental time[sec]	429	408	410	419	410	407	431	416	415
Avg. access distance[m]	558	529	508	442	424	360	403	359	346
Avg. egress distance[m]	240	203	195	268	224	183	269	226	194
Car trips [$*10^3$]	2892	2870	2840	2877	2861	2825	2867	2848	2820
Car trips/vehicle	3.21	3.21	3.20	3.20	3.21	3.20	3.2	3.20	3.19
Avg. car trip length[sec]	472	472	469	473	472	471	473	473	471

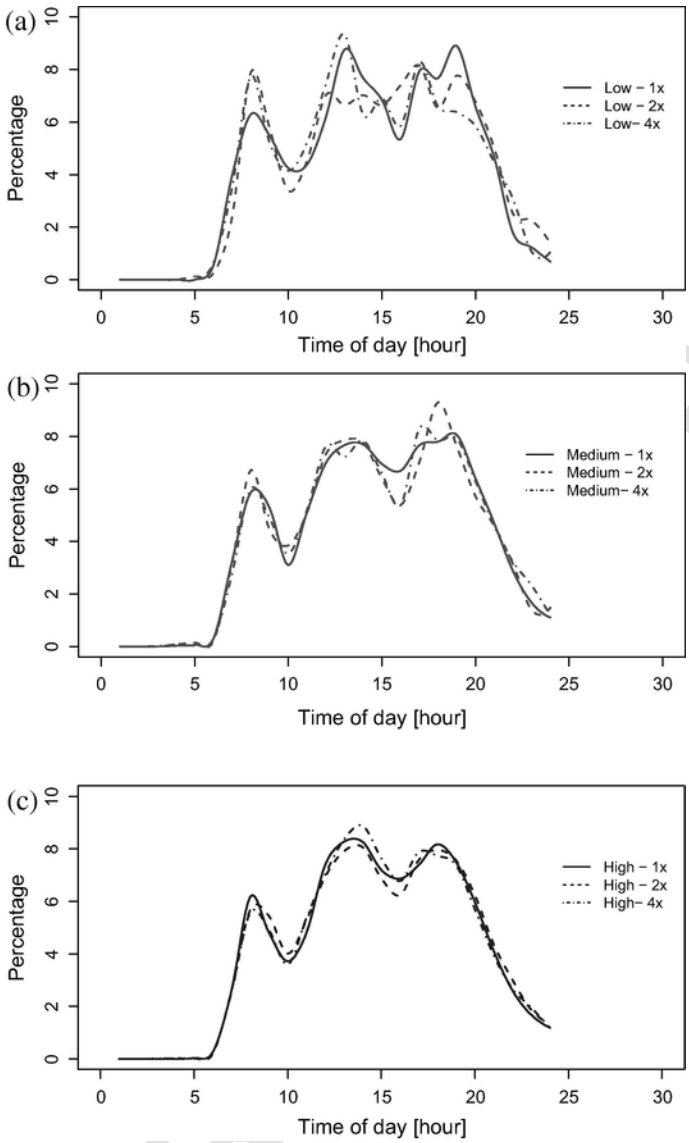


Fig. 5. Rental start times for free-floating vehicles (a) low fleet-size scenario, (b) medium fleet-size scenario, (c) high fleet-size scenario.

servable for the low fleet-size scenarios. In these scenarios, increase in the number of rentals brought by the increase in the parking fees, paired with a non-optimal vehicle coverage because of the small fleet size, might explain these differences for this level of the carsharing diffusion. Moreover, increase of the morning peak is possibly due to more work trips being served by free-floating vehicles, since the parking costs would be quite high with a private car. On the other hand, other peaks get also affected because of the changed distribution of vehicles. This is not occurring for the medium and high fleet-size scenarios because the fleet is large enough to serve the whole service area more efficiently.

Fig. 6 shows the distribution of carsharing trips by purpose for two levels of fleet-size - low and high. Even though, there are very slight differences among the scenarios with the same fleet-size with the increase of the parking prices, there is an evident increase in shopping and decrease in work trips shares when comparing high and low fleet-size scenarios. This is probably because work and shopping locations have different spatial distributions. While work locations are mostly concentrated in the city business districts, shopping locations are spread in the whole area. This, paired with a better coverage of the service area in the high fleet-size scenario provides a better carsharing service for the shopping trips.

Highest spatial concentration of the demand is definitely in the districts in the center of Zurich, where parking is expensive and a lot of activities are performed. This is also where the biggest change in the number of additional rentals per unit of space

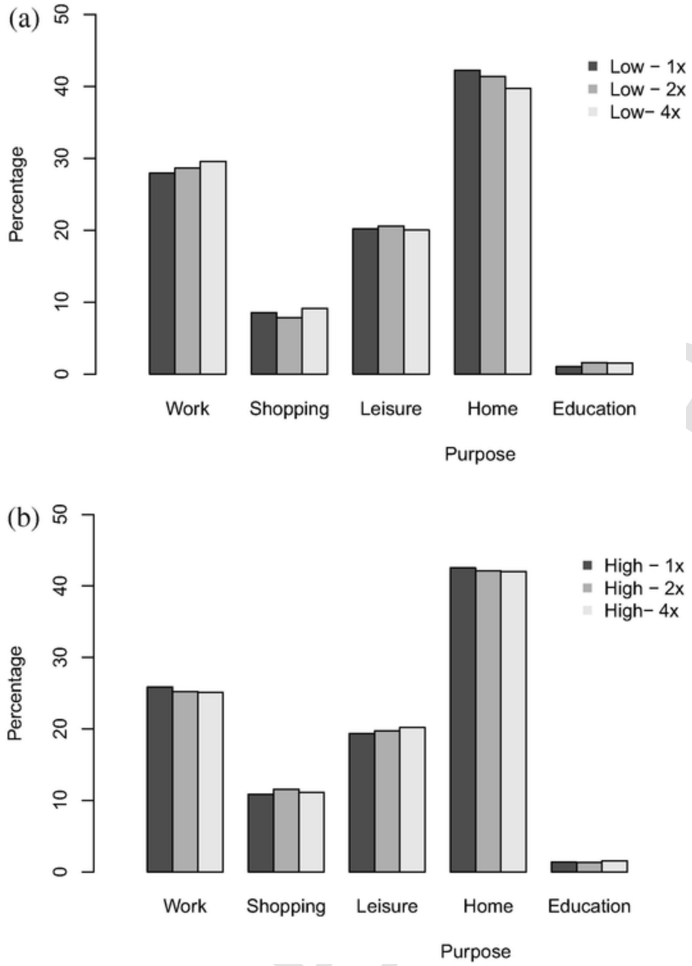


Fig. 6. Free-floating carsharing purpose distribution.

happen when the parking prices are increased. This is true for all three levels of free-floating carsharing fleet-size as can be seen in Figs. 7–9.

Fig. 10 represents spatial analysis of carsharing rentals for low (a) and high (b) fleet-size scenarios. Both figures show the relative change in the number of rentals between the scenario with the original and 4 times higher parking prices. Comparing these two figures, one deduces the following:

- For both fleet-size levels the highest relative change is in the center of the city of Zurich, where the main train station and main shopping and business districts are located.
- High fleet-size scenario has a higher homogeneity when looking at the amplitude of the relative change. On the other hand, in the low fleet-size scenario we observe a substantially higher relative change in the number of rentals in the city center compared to the other areas. This probably arises because of a much higher global utilization of carsharing vehicles in the high fleet-size scenario compared to the low fleet-size one.
- Both scenarios have area with negative relative change (mostly on the outskirts of the city), which might be surprising when looking at the global increase. However, because of the higher utilization and an increased number of users, the rental patterns change and therefore, some of the rental requests that were served before are no longer the best option for the users and they switch to a different mode. This leads to some of the areas with lower demand having a slight drop in the number of rentals. A similar effect was also observed in a previous study that looked at the influence of different pricing schemes for free-floating carsharing (Ciari et al., 2015).

Finally, we performed a spatial analysis of the average parking occupancy by free-floating vehicles in each of the Zurich city quarters. The visualization of these analysis is in Figs. 11–13, for low, medium and high fleet-size scenarios and for two levels of parking prices - original and 4 times higher. In all 6 scenarios the average occupancy is lowest at the center of Zurich, where

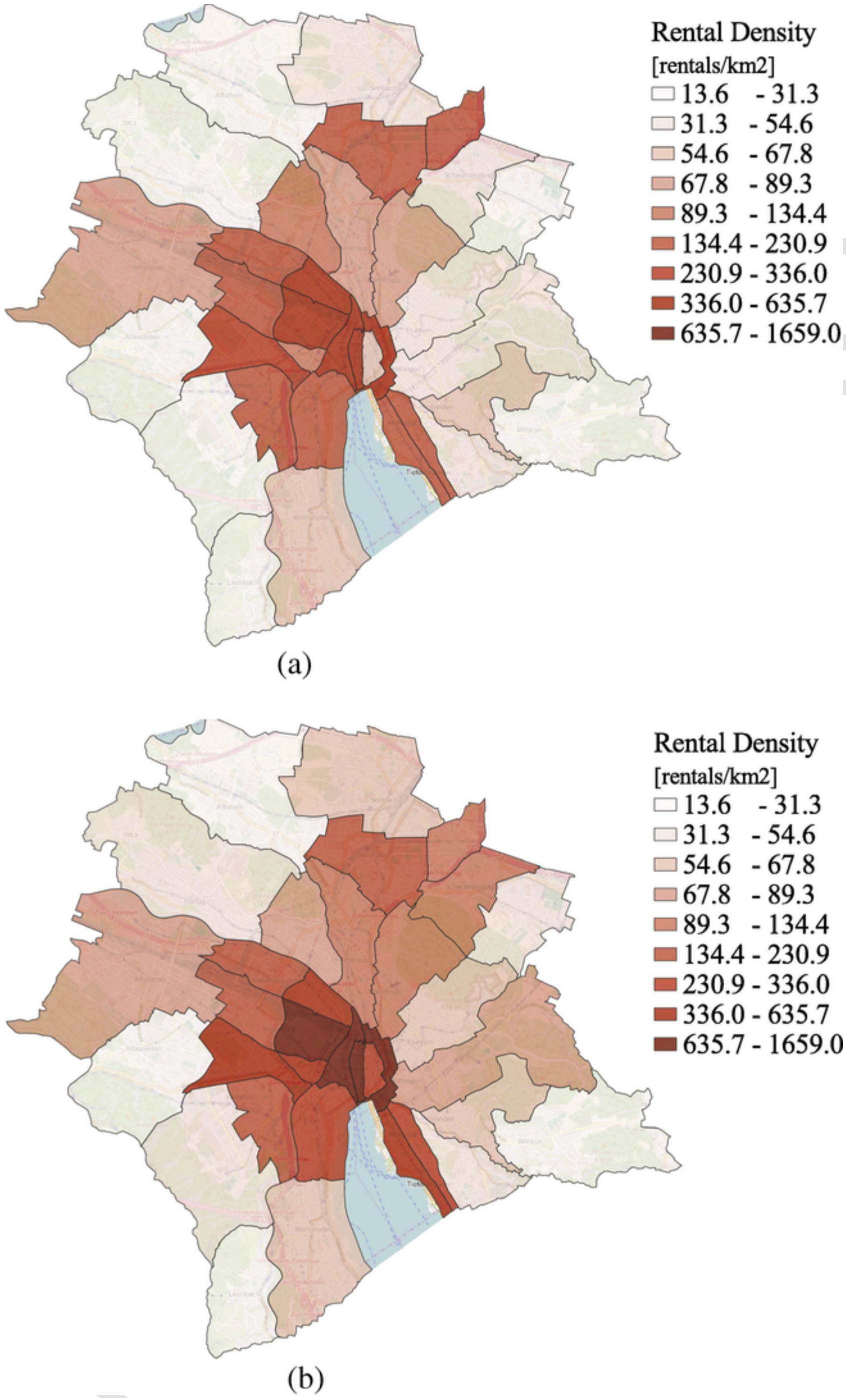


Fig. 7. Rental density with low fleet-size for different parts of the service area (a) original prices, (b) 4 times higher prices.

we also observed the highest demand. This makes sense, since higher demand means higher utilization and re-use of the parked vehicles, therefore their parking time in this area is the lowest. The highest average parking time is observed in the outer regions of the city, which means that in these areas some of the parked vehicles are not used for a relatively long periods of time, which is not a desirable effect. But it is interesting to observe that increasing parking prices reduces the average parking times especially in the outer regions of the city. The reduction of average parking times is quite substantial in the high fleet-size scenario (especially with highest parking prices) where average parking usage is almost homogeneous throughout the service area. This

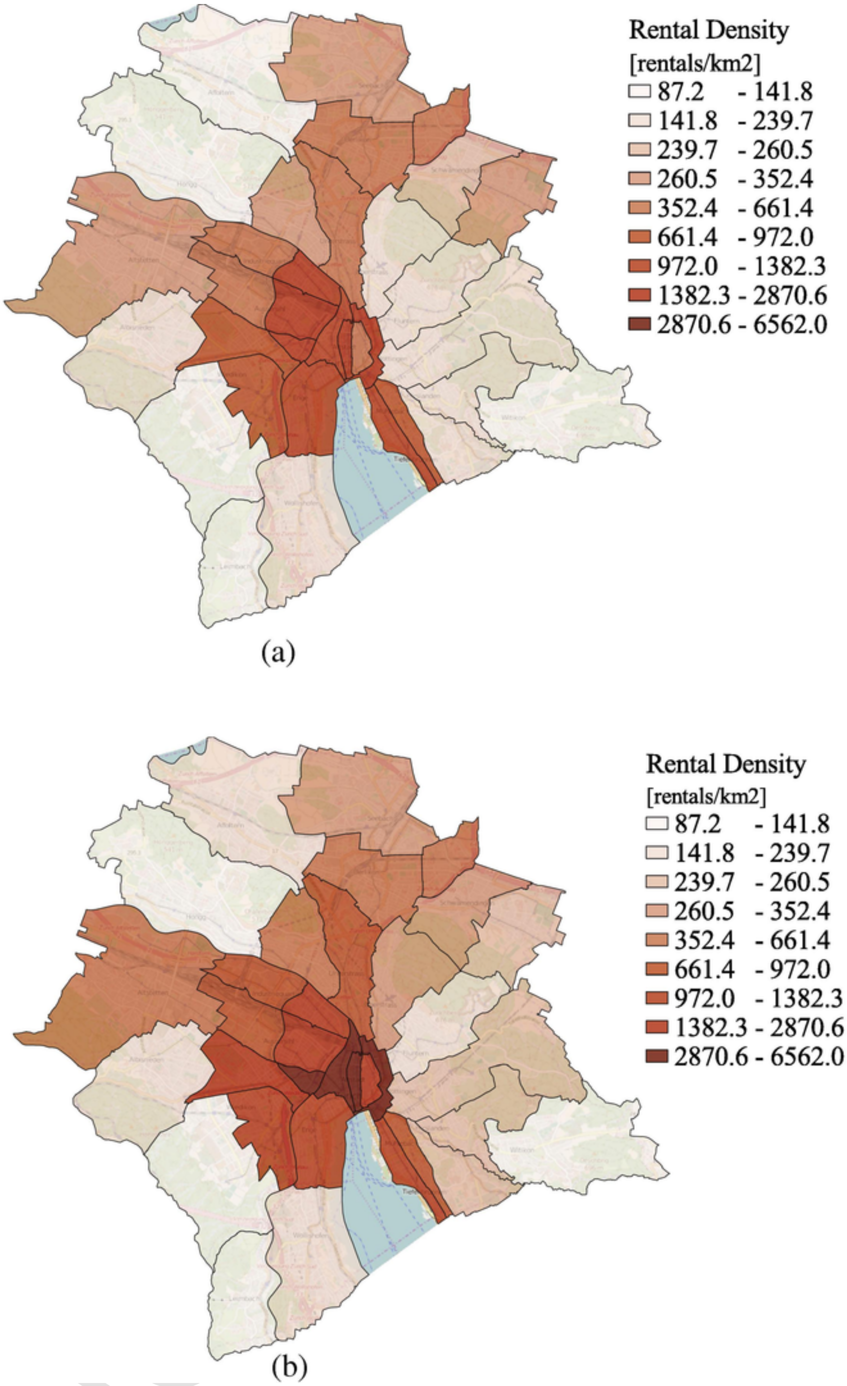


Fig. 8. Rental density with medium fleet-size for different parts of the service area (a) original prices (b) 4 times higher prices.

finding is very important, because it shows that in this scenario the parking space is better utilized and parking pressure peaks are avoided.

7. Conclusions

The main goals of this study were to present a methodology to adequately combine parking and carsharing supply and demand, to show the impacts and implications of different parking prices on free floating carsharing and to deepen the understand-

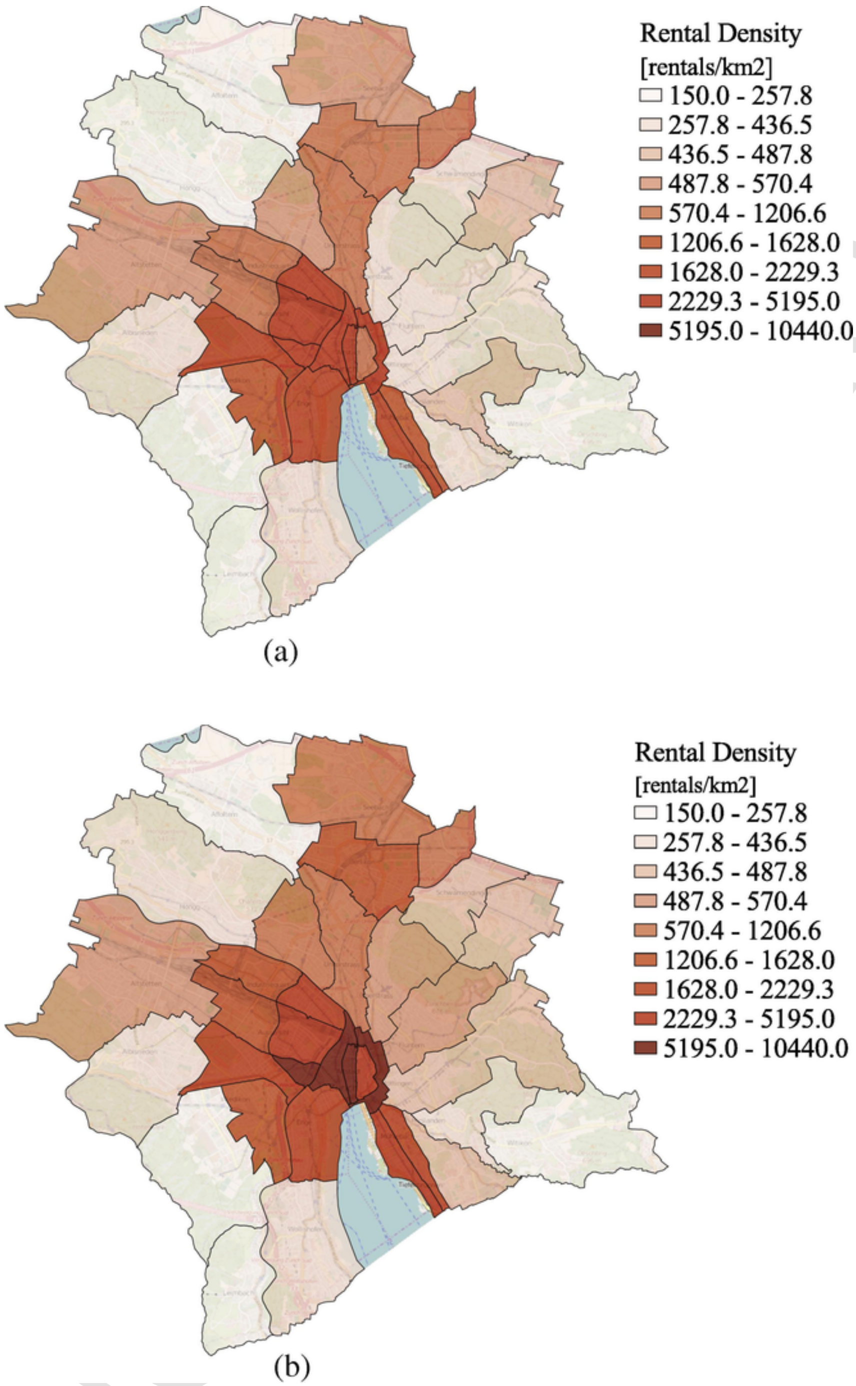
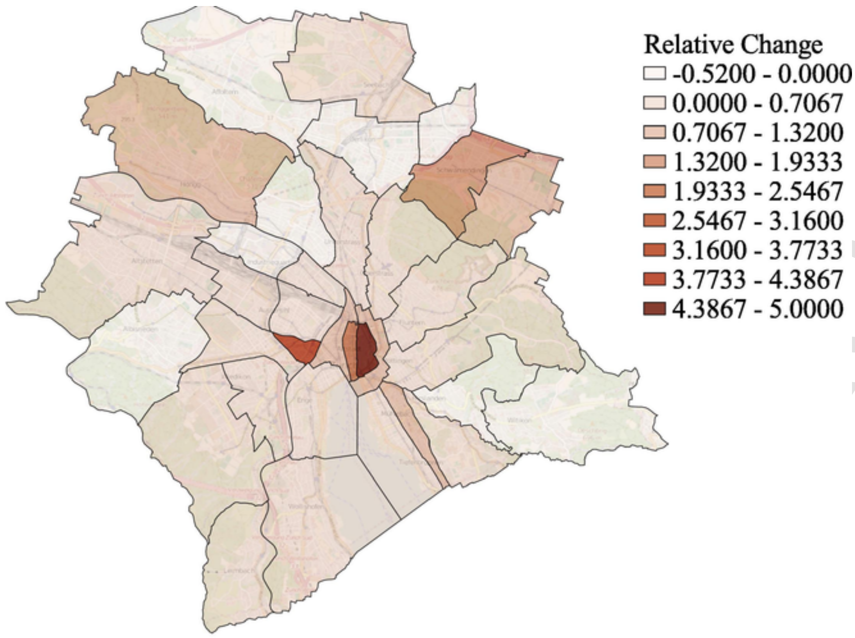


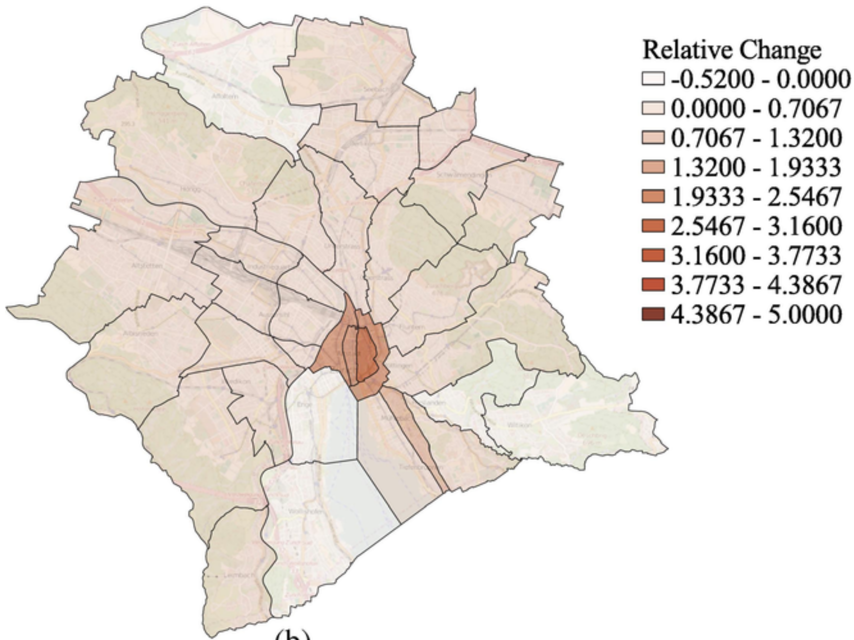
Fig. 9. Rental density with high fleet-size for different parts of the service area (a) original prices, (b) 4 times higher prices.

ing of carsharing effect on parking. In order to do this we made use of multi-agent simulation framework (MATSim), because of its sophisticated nature and ability to cope on a microscopic level with supply and demand for both parking and carsharing.

In a methodological sense, a contribution of the current work is to the best knowledge of the authors a first study to model the mutual dependencies of carsharing and parking on a high spatio-temporal level. Parking is in many cases a very politically sensitive topic and a suitable tool to show the relationship between carsharing and parking is helpful for policy makers in order to address concerns of all stakeholders



(a)



(b)

Fig. 10. Relative change in the number of rentals for different parts of the service area between scenarios with 4 times higher and original parking prices (a) low fleet-size, (b) high fleet-size.

Another contribution of the presented work is to provide an answer to the hypothesis from the introduction - that in the city of Zurich free-floating vehicles can make use of parking space more efficiently than private vehicles. The results of this study suggest that this hypothesis is true and that free-floating cars can not only be utilized more than private cars and therefore reduce their parking time, but also increase the spatial and temporal utilization and turnover of parking slots. Increasing parking fees (especially up to 4 times the current level), brings a much higher homogeneity of the average parking occupancy in the service area. Therefore, the parking pressure peaks are avoided and the available parking space is utilized more efficiently.

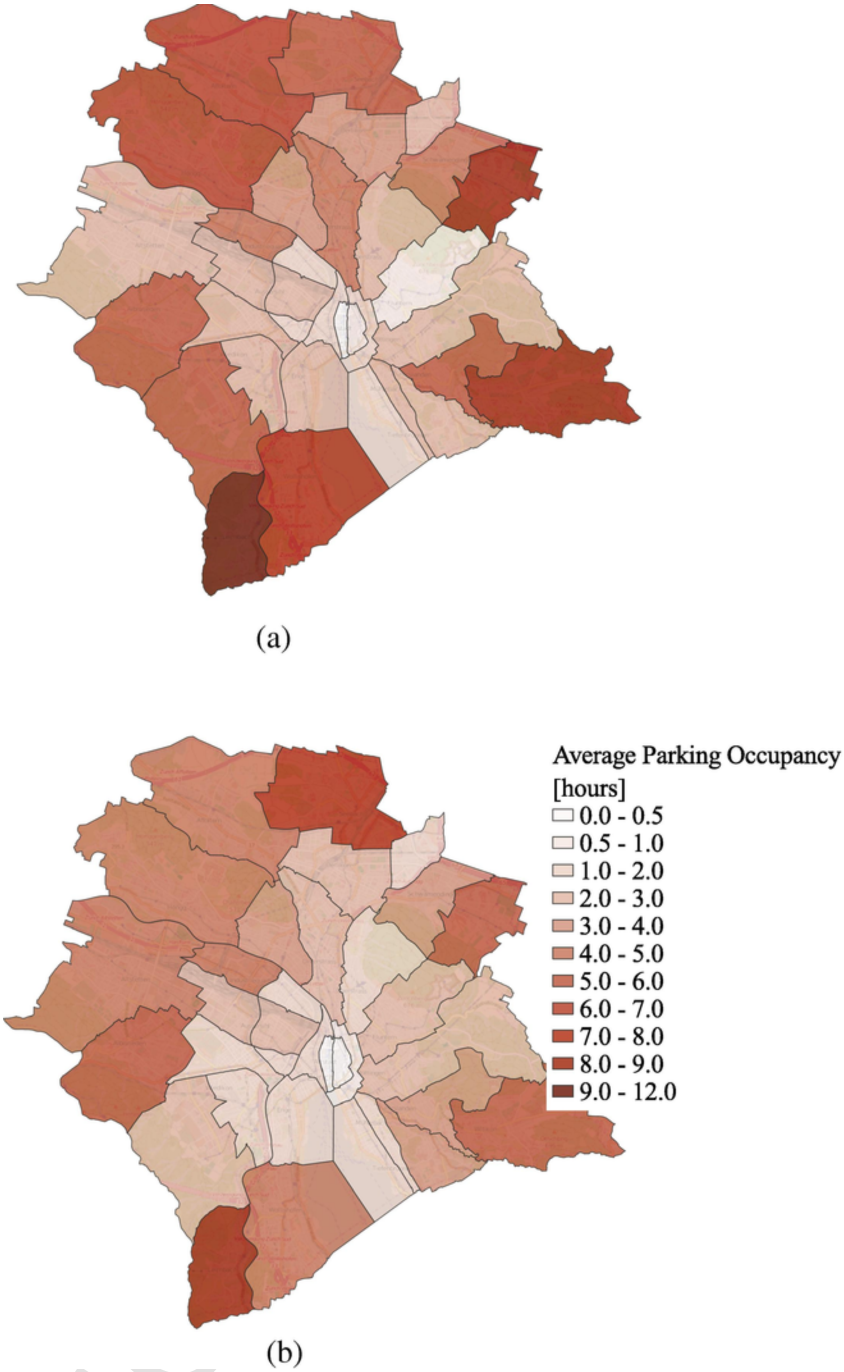


Fig. 11. Average parking occupancy by free-floating vehicles for different parts of the service area for low fleet-size scenarios (a) original prices, (b) 4 times higher prices.

One of the limitations of the current work is not modeling rentals which include stopovers, even though the implementation of the infrastructure is available. We avoided using rentals with stopovers since we did not have any useful empirical data that can be used as a basis for a model. This will be improved and proper models developed when enough of the empirical data is collected on the study currently conducted for the free-floating service in Basel. Further improvements of the proposed method would include a better calibration of the parking model by introducing monthly permits for agents, developing a more sophisticated membership model for free-floating carsharing and introducing individual preferences to agents.

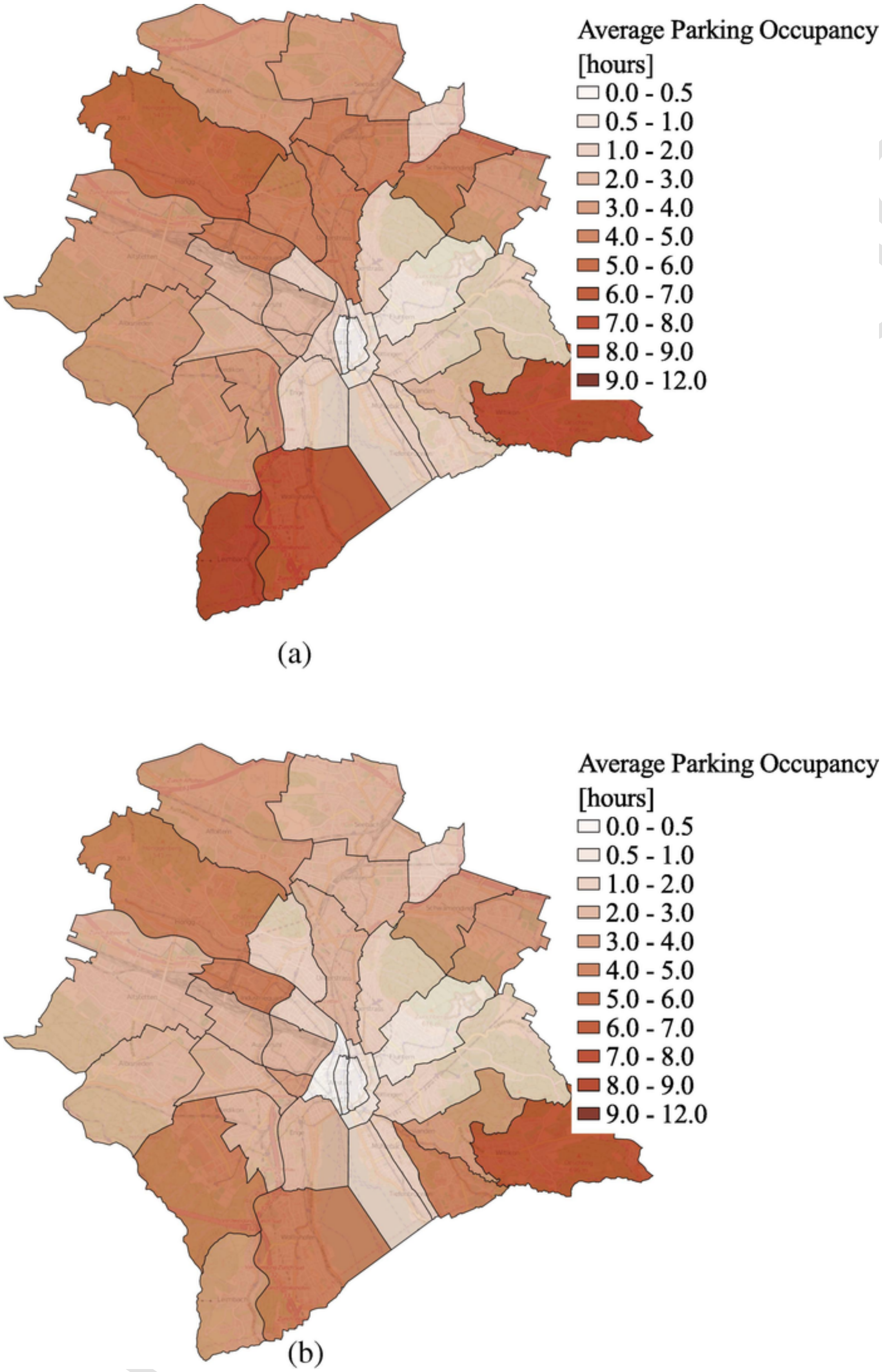


Fig. 12. Average parking occupancy by free-floating vehicles for different parts of the service area for medium fleet-size scenarios (a) original prices, (b) 4 times higher prices.

8. Uncited reference

Kelemen (2004).

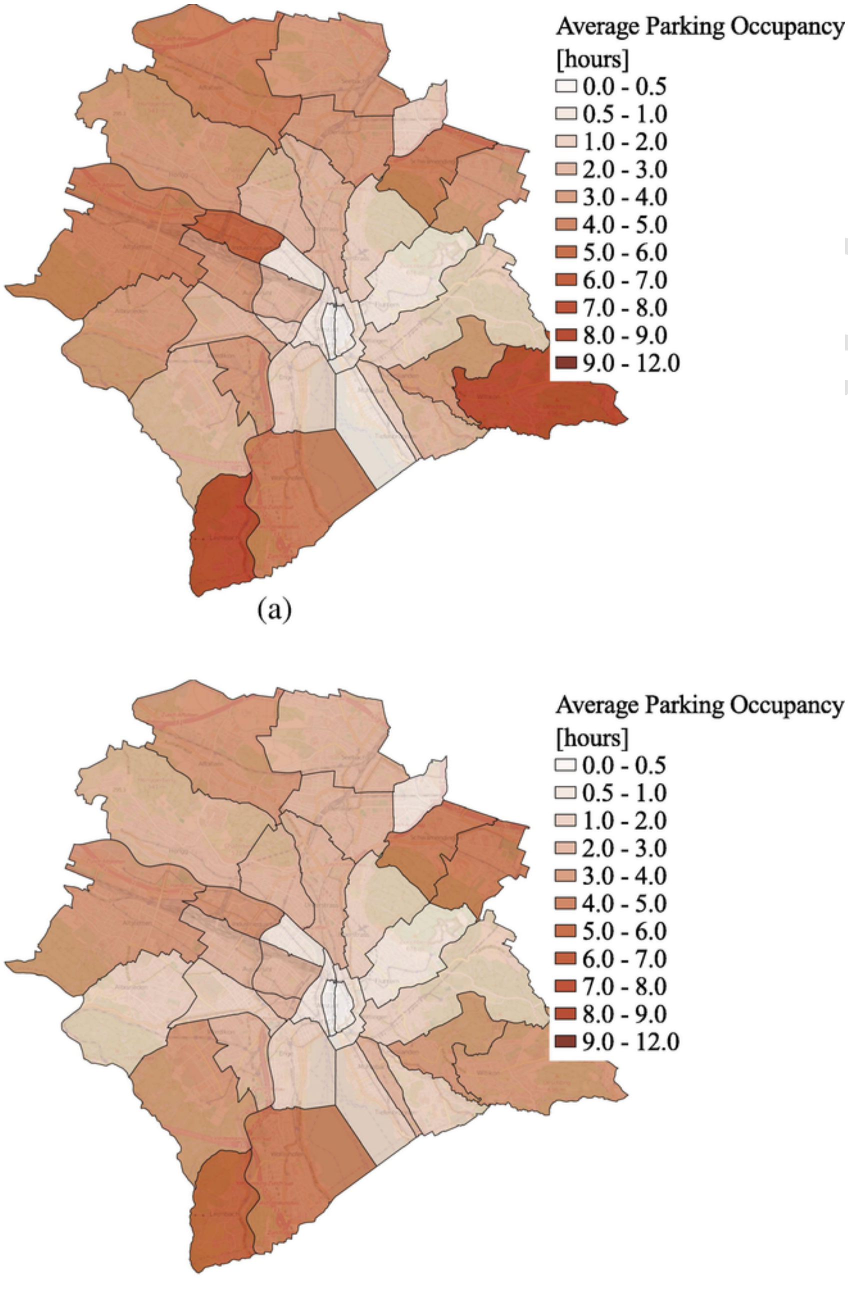


Fig. 13. Average parking occupancy by free-floating vehicles for different parts of the service area for high fleet-size scenarios (a) original prices, (b) 4 times higher prices.

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