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Assessing Two-way and One-way Carsharing: an Agent-Based Simulation Approach

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Abstract

Carsharing companies can customize their service by adopting different pricing schemes and offers with the aim of increasing fleet use and profits. Different business models have been developed such as round-trip and one-way. It is clear that, even though many aspects of the business model and operations are the same, the different way in which these services are supplied leads to a diverse response from the users. In this work, we analyze how a fixed pricing scheme affects the behavior of the members of two different carsharing systems: two-way and one-way, explicitly considering their different income distributions to analyze social equity aspects. The dynamic pricing policy is simulated in MATSim, an agent-based simulator able to generate realistic mode choices based on individual activity-travel behavior. Scenarios with a synthetic population of carsharing members for the city of Berlin are analyzed. We aim to provide an experimental analysis that addresses the different behavior of different demand sectors, categorized by income, in function of the supply distributed on the territory. Simulation results show that the two services are not in competition between each other: the two-way service is used as a substitute for private cars while the one-way system is preferred from agents who choose to use multiple types of modes during the day. The response from the different income classes tends to be similar for both services since all the users within the same purchase power have the same degree of acceptance for both systems.

Keywords: Car-sharing; Agent-based Simulation; Mode Choice

1. Introduction

In order to tackle sustainability and traffic congestion issues, companies and public institutions are showing a growing interest in new mobility solutions, in particular sharing services (car sharing, carpooling, park sharing), on-demand ride-hailing services (Call-a-bus, Uber, etc.) and mobility-as-a-service (e.g. Whim). Coordinated efforts are

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being made to match mobility needs with sustainable mobility services in order to fight car dependence. Indeed, carsharing vehicles contribute to the creation of more sustainable cities given their better fuel efficiency if compared to private cars (Martin and Shaheen, 2011).

Traditionally, carsharing services are differentiate between one-way (station-based and free-floating) and two-way system. On one hand, these two systems share a lot of similarities in reducing externalities such as emissions and car ownership (Martin and Shaheen, 2011) while, on the other hand, the way they are used by the users can be different. This gives rise to different streams of research that, most of the time, treat these two services independently. In a study conducted by Ferrero et al. (2018) it is shown how the most studied stream of research for the one-way is the fleet-management while for the two-way the focus is more on the infrastructure design related to the parking location strategies.

Works regarding simulation comparing both systems at the same time are rare. Lempert et al. (2019) and Namazu and Dowlatabadi (2018) focus their work on a survey based approach in order to define, respectively, the impact on car ownership and the reasons leading users to choose for a carsharing membership for both two-way and one-way systems. Cisterna et al. (2019) adopted a combined simulation and discrete analysis approach to study the membership choice of two carsharing systems, two-way and one-way free-floating. In order to get an insight into the relationship between fleet size and demand, Orbe et al. (2015) evaluate the effect of variable user demand on a two-way and one-way (both station-based and free-floating) carsharing fleet in Zurich using agent-based simulation.

As already mentioned, one of the expected long-term benefits of carsharing is the reduction of vehicle ownership bringing to their members new ways of moving in their cities, but it is not clear yet if these benefits can be considered equally distributed. Studies reported that vehicles cluster in areas that are densely populated by young residents with high levels of education Tyndall (2017), making the service more available to those segments of the population that are already socially advantaged. From a policy point of view Shaheen, et al. (2017) describe how sharing mobility may provide spatial and temporal resolutions to bridge the transportation gaps by providing a first-and-last-mile connection to the traditional public transportation network, by reducing waiting time and by increasing travel-time reliability.

Even though, to the best of authors' knowledge, studies that address the equity in carsharing through a simulation approach, are very uncommon, methods that study equity with an agent-based simulator are more popular in the literature. Concerning road-pricing, Grether et al. (2008) look at the effect of an afternoon toll on a synthetic population and how the change in price affects their consumption patterns. Using road pricing, Lucas Meyer de Freitas et al. (2016), analyze winners and losers of a congestion pricing scheme for the city of Zurich.

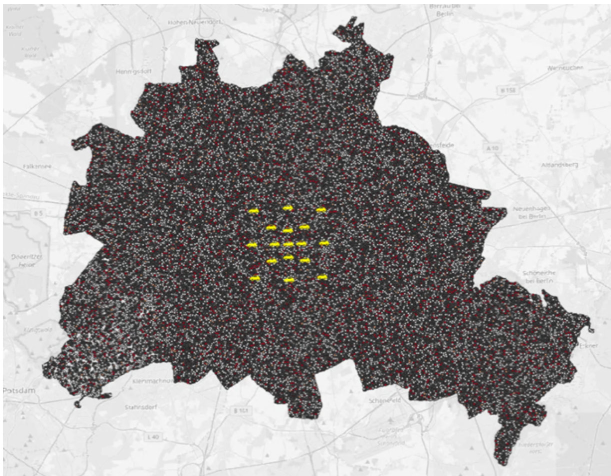
In order to bridge the different gaps described in this section, the goal of this work is to introduce a comparative analysis between a two-way and one-way carsharing services using financial and operational key performance indicators (KPIs) to assess the systems' behavior from the supply perspective, and equity- and travel-related KPIs to determine the response of the demand using economic-sensitive variables collected through an agent-based simulation.

2. Methodology

Regarding both two-way (TW) and one-way (OW) carsharing systems, it becomes clear that a trip-based model is not employable to assess important KPIs such as service availability at a precise point in space and time (Ciari et al., 2014). Additionally, disaggregated methods are necessary to describe the behavior of the individuals and the activities executed at different locations and at different times. That is why, in order to assess single user's behavior, an agent-based modeling approach is used. In this work we adopt agent-based simulation to analyze a TW and a OW carsharing system on the Berlin network, following a well-established stream of research in the field, which adopts a similar methodological approach (Lopes et al., 2014; Laarabi et al., 2017). The agent-based simulator chosen to perform this assessment is MATSim. "MATSim is an activity-based, extendable, multi-agent simulation framework implemented in Java. The framework is designed for large-scale scenarios […] and based on the co-evolutionary principle" for optimizing the agents' activity schedule (Horni et al., 2016). The open-source nature and the presence of an ad-hoc carsharing contribution for the software made it the most suited software to be used for our analysis. The scenario used for the simulation is derived from Ziemke D. and Nagel K. (2017). It consists of a synthetic population representing approximately 8% of the inhabitants in the region of Berlin and Brandenburg, Germany. Using QGIS, a free and open-source cross-platform desktop geographic information system, we exported the synthetic population for the sole city of Berlin, roughly 280000 agents.

2.1. Introduction of the Value of Time

Using the Berlin micro census data (Amt für Statistik, 2017) we distributed the income on the synthetic population following the income distribution per neighborhood. Introducing the income as the only sensitive variable would not be sufficient, what could make one choose for a mode of transport instead of another is the value of time saved by doing that choice. For this reason, the value of time (VOT) is chosen as parameter and it is applied to the population following the procedure illustrated in Giorgione et al. (2019) based on the values retrieved from Axhausen et al. (2015). We obtain the sysnthetic population in Fig.1. Carsharing stations were located randomly within the Berlin central area as shown, in yellow, in the same figure. The reason behind this choice was to place stations where density is the highest, to evaluate whether people living far from the stations used the service and to keep the same number of stations used in the previous work (Giorgione et al., 2019).



Agent VOT [€/h]	Agent Color Code
4,00	
3,00	
2,00	
0,50	

Fig. 1. (a) first picture; (b) VOT and color code.

The information regarding the VOT was introduced in the *plans* file. This file - generated from census data - consists of the complete list of agents with their respective activity-chains. Furthermore, every agent is portrayed with a system of attributes (e.g. person ID, gender, age, license, car availability and employment status). Every user is described by its personal activity schedule with attributes such as activity type, coordinates of the location where the activity takes place, temporal duration of the activity and mode of transport used to reach a determined facility.

As already observed, to determine the economic effects of two distinct services on different income classes, it is important to include a variable sensitive to this transformation. To incorporate this variable in MATSim we introduce the VOT in the scoring function:

$$S_{plan} = \sum_{q=0}^{N-1} S_{act,q} + \sum_{q=0}^{N-1} S_{trav,mode(q)}, \quad (1)$$

With N as the number of activities. Trip q is the trip that follows activity q (Horni et al., 2016). The scoring is a measure of the utility a user gets to perform a specific activity at the desired time using a precise mode of transport. In equation (1) this is defined by the score of a plan (the ensemble of all the daily activities executed by an agent), which is the sum of $S_{act,q}$, the score generated doing an activity and $S_{trav,mode(q)}$, i.e. the disutility of travelling. For every agent, the first term has the same form as in the next equation:

$$S_{act,q} = S_{dur,q} + S_{wait,q} + S_{late,ar,q} + S_{early,dp,q} + S_{short,dur,q} \quad (2)$$

where the five contributions to the scoring consist of the utility of performing an activity, the waiting time spent before starting an activity, the late arrival penalty, the cost for not staying long enough and a penalty from a 'too short' activity (Horni et al., 2016), respectively. The VOT is introduced in the first addend:

$$S_{dur} = (\beta_{dur,q} * t_{typ,q}) * (\alpha_{VOT} * VOT) * ln\,(t_{dur,q}/t_{0,q}), \quad (3)$$

Where $t_{dur,q}$ is the performed activity duration, $\beta_{dur,q}$ is the marginal utility of activity duration and $t_{0,q}$ is the duration since the utility starts to be positive (Horni et al., 2016). In equation (3) we introduce the VOT and α_{VOT} as a scale factor for the VOT. Since the VOT is evaluated *ex-ante*, we are introducing the concept that an activity will produce more value if the person doing that activity gains a higher value from it, this value is, as explained before, directly linked to the income.

2.2. Carsharing

In this analysis we aim to assess the response of a set of users of two different types of carsharing services. Concerning the ability to use both carsharing services, the demand is considered elastic. Carsharing is a membership program, that means customers can use the service only if they meet some specific requirements (e.g. they hold a driving license). In this study every agent holding a driving license is allowed to use the carsharing as an additional mode of transportation and, moreover, this mode can be used for a subtour or for the complete trip chain.

While the concept at the base is the same, the two systems differs on how the service is provided, the pricing model and the fleet composition. We created 17 stations for both services and placed them at the same geographical location.

As described in Münzel et al. (2018), the TW service tends to have few cars. That is why we allocated two cars per station. The pricing model consist of a fixed price rate of 6 euros per hour and unlimited kilometers. As the price is paid by the hour, we introduced a grace period of 5 minutes. The hour is charged as a whole if the booking time exceeds this grace period. OW services have a larger fleet (Münzel et al., 2018), this is why in this case we allocated 8 cars per station. The pricing model consist of a fixed price rate of 0,25 euros per minute while moving and of 0,10 euros per minute in case of a stop without dropping the car.

3. Results

The following results are divided in two sections describing the response of the demand from an equity and individual perspective and the response of the supply system from an operational point of view.

3.1. Demand Response Analysis

With equity we refer to fair and balanced distribution of resources among the population. Hence, we assess in which measure both services are accepted among the population, when the latter is subdivided by VOT.

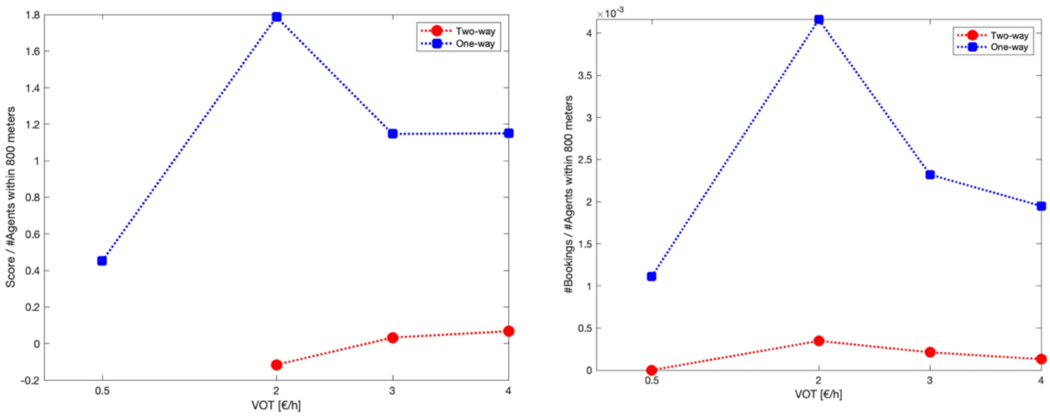


Fig. 2. Average (a) score and (b) bookings per VOT class

Fig. 2a shows the average score over the number of agents located at walking distance from the carsharing station and clustered by VOT. A first observation is that no agents with a VOT of 0.5 (lowest income in the simulated population) opted for the two-way service. Similarly, Fig.2b shows the number of bookings on the number of agents at walking distance from the carsharing station clustered by VOT. The response of the demand appears to be fairly similar for both services, i.e. low VOT class tend to benefit less if compared to other classes, resulting in an ascending trend. The higher value of scores and bookings for the VOT of 2 €/h is due to the relatively higher pay off the agents in this class have in using the carsharing and, possibly, to the significantly smaller number of agents (Table 1) living around the stations.

Table 1. Number of agents living within 800 meters from a carsharing station

VOT [€/h]	# Agents
0.5	3392
2	885
3	14222
4	15403

Concerning the number of bookings for both services, Fig.2a shows how agents with the same VOT have a similar behavior when using the TW and the OW systems meaning that one service is not more equitable than the other. To assess the bookings distribution during the day, we show the demand profile of the users in Fig. 3a.

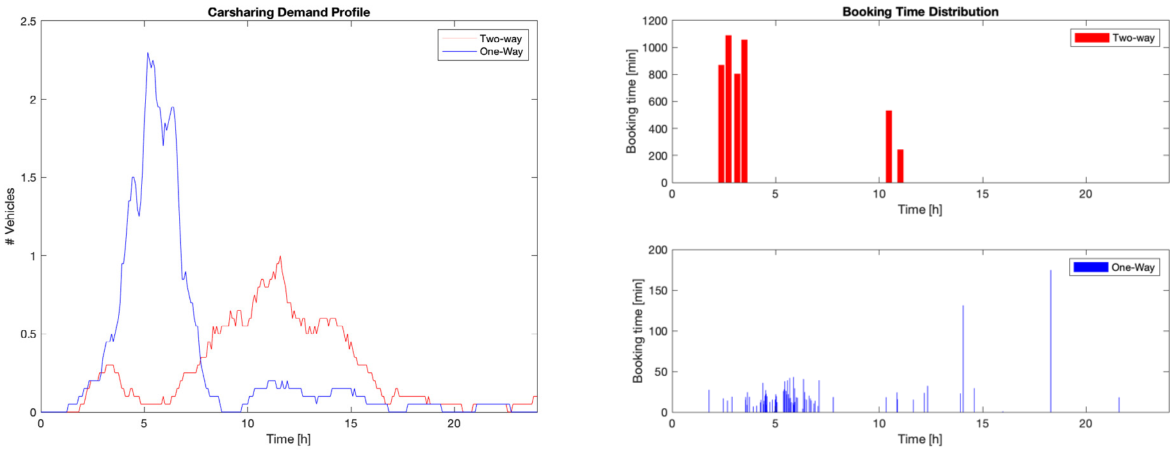


Fig. 3. (a) Demand Profile; (b) Booking Time distribution

This profile indicates clearly distinct mobility patterns: whilst OW users tend to book a car mainly before and during the morning peak period, TW users reveal a peak in the demand after the peak period. This suggests that OW users book the car, in the morning, for commuting trip purposes, whereas TW users adopt the service for other activities than going to work. This is to be expected, since work is a high-value and long-duration activity and arriving on time is more desirable compared to other activities. As described in Fig. 3b, TW users book the car in the morning using it throughout the day (with an average booking time of 13 hours for bookings happening in the early morning until 8 a.m.) while OW users opt for the carsharing service both for commuting (with an average booking time of 20 minutes for bookings starting in the early morning until 8 a.m.) and other activities. The chance of using the OW carsharing system allows agents to go to work and to leave the car in order not to pay a parked vehicle during their working hour; moreover, other cheaper types of transportation can be used to execute other activities characterized by lighter penalties for late arrival. The TW system is more used in the middle of the day, usually for activities far from the city center. Indeed, in Fig. 4a we show that the use of a TW carsharing service is not dedicated to a specific activity.

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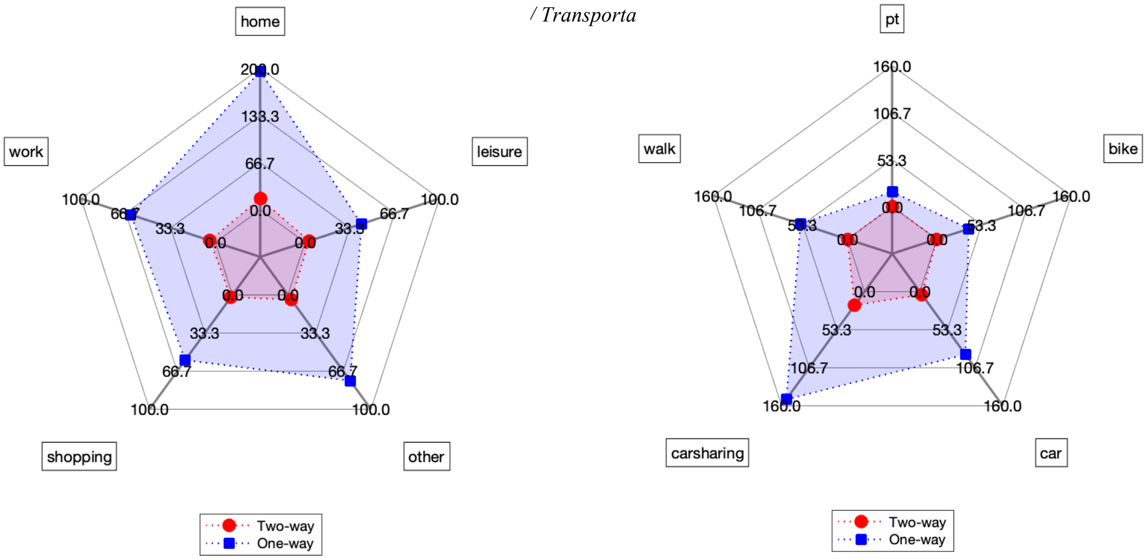
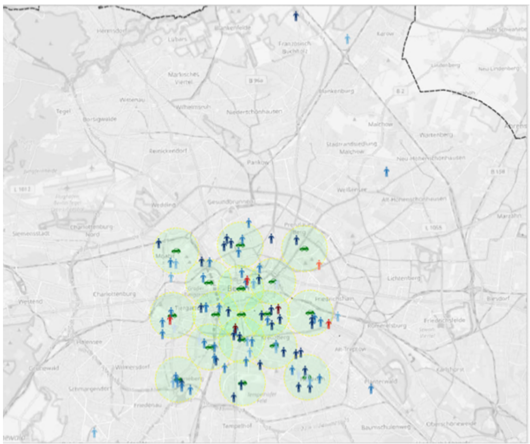


Fig. 4. Number of (a) activities executed; (b) mode used

Fig. 4 shows the behavior of the agents who used the carsharing at least once during their daily schedule. Fig. 4a shows an axis by axis comparison of the mode used. Concerning the one-way carsharing, we can see how this mode is not used to execute any activity in the specific. More insights come from Fig.4b where the nature of these two services is shown: the TW system is used as substitute for all the other modes while the OW integrates with other means of transportation. In general, agents, tend to prefer and book more the OW system. The average score for the TW and OW system is, respectively, 195.26 and 513.76 with a variance of 300.86 and 476.18. The OW service has a higher mean which suggest a greater utility for the agents using this system.

In Fig. 5 we show the booking distribution on the territory. This shows where people using the services live.



VOT [€/h]	Two-way	One-way
4,00		
3,00		
2,00		
0,50	No bookings	

Fig. 5. Territorial distribution of booking per VOT and carsharing service

The OW service is used even from people living far from the stations, this reinforces what is shown in Fig. 4b: OW carsharing can be used inside a multi-modal journey while the TW service is used only by people living nearby a carsharing station.

Even though all evidences produce a more favorable results for the OW service from a user's perspective, analyzing the results of the simulation from the provider standpoint can lead to a wider understanding of the phenomena created by the implementation of these two services.

3.2. Analysis of Carsharing Operations

As a service provider, companies' main KPIs can be broken down into fleet management indicators such as number of bookings, distance, booking times and economic indicator like revenue, kilometric and hourly gains. In Fig.6 we show the overall KPIs for both the carsharing services.

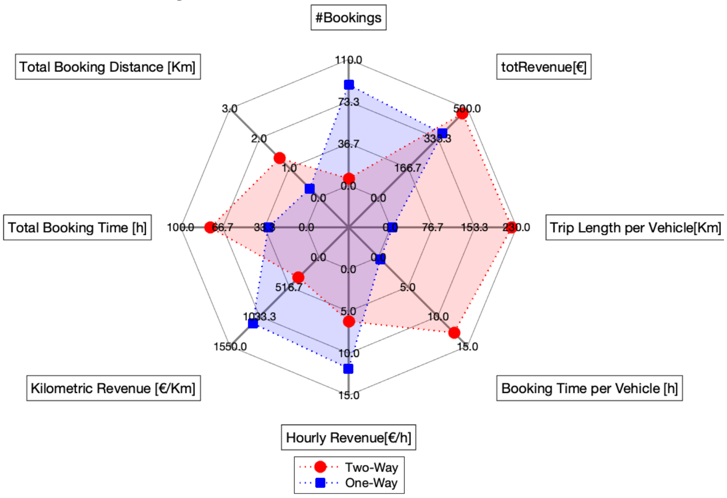


Fig. 6. Provider's KPIs.

The disparity in number of bookings is more evident in this last figure. 88 vehicles were booked on the OW service against only 6 in the TW. This resulted in higher kilometric and hourly revenues for the former, especially considering that booking times and distances are way lower than the latter service. Even though the number of bookings is significantly higher, the OW system cannot reach the same total revenue as the TW service, the average trip length (around 3 kilometers and half for the OW and 220 kilometers for the TW) and the average rental times (20 minutes for the OW and almost 13 hours for the TW), bring a higher revenue even though the number of vehicle offered by the service is significantly lower. The TW system provides vehicles that are booked for longer times and that time is paid by the final user.

For a further assessment of the competition among the two system we have run two other simulation making one service available at the time for the same carsharing members.

Table 2. Number of agents booking for different Scenarios

Scenario Code	Scenario	Two-way Bookings	One-way Bookings
1	Two-way + One-way	6	88
2	Two-way only	7	-
3	One-way only	-	78

The difference between the main scenario (two-way + one-way) and the "two-way only" one is negligible. For the "one-way only" the difference is higher, but the number of users is not increasing. Moreover, in any case no agent is going to use both service in any of the simulation. In the end, 40 % of the agents using the OW service in the scenario 1 are using it again in scenario 3 while none of the agents using the TW service in the scenario 1 are using the service again scenario 2.

4. Conclusions

Assessing TW and OW carsharing system in the area of Berlin leads to a diversified response from the users' community that does not appear to be based on their purchase power. Users with similar VOT have the same behavior in terms of number of bookings made when using both services with a similar scoring trend, meaning that their VOT classes have the same group response in term of utility.

The services are substantially different, they are used for different reasons and they are not in competition in terms of customer profiles. The TW system is used mainly as substitute of a private car and, considering the number of bookings, is a niche service for the transportation system. Overall, the price of 6 euros per hour appears too high when compared to other alternatives; this effect is even intensified by the time frame of the MATSim simulation: it simulates one day of activities and does not have the ability to take into account long term mobility decision.

TW users' behavior shows how the implementation of this service can reduce car ownership but, in terms of sustainability, the only contribution can come from a more efficient car fleet (newer vehicles are less polluting) or from using electric vehicles. Differently, The OW system is seen as an integration to the modal offer available in the area. Indeed, this service is more sustainable and can alleviate congestion by increasing the number of trips made with different type of modes.

On one hand, the OW can be considered as a greener sharing service but, on the other hand, it is clear how the low distance travelled, revenue and booking time lead to smaller income on the operator side which, without a good system of subsides, could hardly generate profit.

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