Comparison of free-floating car sharing services in cities

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Abstract

In recent years, free-floating car sharing services (FFCS) have been offered by many organizations as a more flexible option compared to traditional car sharing. FFCS allows users to pick up and return cars anywhere within a specified area of a city. FFCS can provide a high degree of utilization of vehicles and less usage of infrastructure in the form of parking lots and roads and thus has the potential to increase the efficiency of the transport sector. However, there is also a concern that these compete with other efficient modes of transport such as biking and public transport. The aim of this paper is to better understand how, when and where the vehicles are utilized through logged data of the vehicles movements. We have access to data collected on FFCS services in 22 cities in Europe and North America which allows us to compare the usage pattern in different cities and examine whether or not there are similar trends. In this paper, we use the collected data to compare the different cities based on utilization rate, length of trip and time of day that the trip is made. We find that the vehicle utilization rates differ between cities with Madrid and Hamburg having some of the highest utilization levels for the FFCS vehicles. The result form a first step of a better understanding on how these services are being used and can provide valuable input to local policy makers as well as future studies such as simulation models.
**Introduction**

Transport is one of the key sustainability challenges of cities since it affects both global issues such as climate change and local problems such as pollutants (e.g., PM and NOx), congestion, distribution of urban space as well as health issues (Bulkeley and Betsill 2005). These challenges call for a shift to sustainable mobility patterns by reducing vehicle ownership and use, as well as introducing cleaner technologies. Mobility services such as car sharing have been suggested as one of the solutions to the problems, since they can provide a high degree of utilization of vehicles and less usage of infrastructure in the form of parking lots and roads and thus have the potential to increase the efficiency of the transport sector.

However, the penetration rate, while growing, is still quite low. In recent years, free-floating car sharing (FFCS) services have been offered by many organizations as a more flexible option compared to traditional car sharing. FFCS allows users to pick up and return cars anywhere within a specified area of a city. These services are mainly introduced in Europe and North America and are well-established in e.g. in several German cities. The services are dominated by two larger operators: Car2Go and DriveNow/ReachNow. Globally Car2Go is present in 30 cities and DriveNow/ReachNow in 14 cities. Besides these operators, there are also smaller companies that operate in just one city or country.

The research on FFCS is in its early stages. Many aspects of these services and their effects on society are not known with certainty. The majority of the research is based on surveys or simulation (Ciari et al. 2014; Firnkorn and Müller 2011; Firnkorn 2012; Kopp et al. 2015). There are few studies that use revealed data on FFCS. Kortum and Machemehl (2012) analyze spatial characteristics of cities with car sharing, both traditional and free-floating. They find that high population, small household size, high transit use, and high levels of government employment are the characteristics of a city with a high potential for car sharing. They also predict membership and the market share of these services. Kopp et al. (2015) compare, among others, the differences in spatial characteristics of where FFCS and non-car-sharing (NCS) users reside. FFCS users live in denser areas with a better local supply of facilities. Despite better accessibility to public transport, FFCS users use it to the same extent as NCS users do.

Schmöller et al. (2015) investigate the usage of FFCS in the case of Berlin. The results show that the demand is mostly concentrated on a few temporal peaks and spatial Hot Spots. Our study is similar to the one made by Schmöller et al. (2015). However, while we investigate the same research questions about usage pattern, we use different methods. Moreover, we have access to the data of 22 cities which allow us to compare the usage pattern in different cities and examine whether or not there is a similar trend, none of the previous studies have done this. Also, to our knowledge, few studies of FFCS, besides Schmöller et al (2015), look at actual usage patterns of the vehicles.

In this paper, we study the actual usage of FFCS by analyzing a data set with 27 million trips. We use an explorative approach to try to understand how these services are used in different cities. It should be noted that this study is descriptive. We do not aim to answer the question of why the usage patterns are different in various cities but rather the question of how these patterns differ. Therefore, we do not compare the underlying factors that may lead to different usage patterns in the cities such as population density, public transport performance or car ownership. The primary purpose of this study is to identify similarities and differences of usage pattern and not to assess if the service is successful or not. While not conclusive, these results can be valuable input for future studies to identify which cities might be of interest for further investigation, to simulation studies and to policy makers that wish to understand how the service function in their city compared to others.

In the first step, we compare different usage variables, such as average duration of trips and utilization rate, between 22 different cities. In the next step, we look at when the vehicles are used - is it mainly during rush hour or at other times? Finally, in the last step it is investigated where the vehicles mostly are used, and if the driven distances easily are covered by public transport.

**Data**

Free-floating car sharing services are inherently reliant on information services to inform their users about the present position of available cars. Information about the present position is, at least when parked and non-booked, provided by the vehicle to the operator and made publicly available through web-pages and/or smart phone applications to enable the user to find and book available vehicles, see e.g. Figure 1.
Reservation of a vehicle requires that the user application is aware of the vehicle identity, which makes it possible to identify movements of individual vehicles. Start location for each movement corresponds to the sample before the vehicle is no longer indicated as available to the user and end location corresponds to the first sample where it once again can be booked. To enrich the user experience further, information on vehicle type, powertrain, cleanliness and fuel level is often provided by the operator via their websites and mobile applications.

The base dataset consists of vehicle availability data sampled between 2014 and 2016 from 3 different operators in 22 different cities located in Europe and North America with sampling time of 60 seconds. In total, approximately 27 million vehicle movements have so far been identified.

The data contains the following variables for each trip during the data collection period: vehicle ID, starting and ending time of the booking, vehicle make and model, the position of vehicles at the start and end time, fuel/energy level at the beginning and end time, fuel type (electric/ gasoline/ diesel).

While we have ample information on the position of the vehicles, at least when parked and non-booked, we lack information from the user perspective and the city level at this stage, limiting the questions that can be directly answered through this analysis. The study in this paper should be seen as a first step analysis. At the moment, we are collecting further data on city level to be able to better understand the underlying factors.

**Methods**

Each city is analysed separately and averages and standard deviations are calculated for number of trips per day and vehicle, the distance of the trips and the duration of trips. The number of vehicles in the FFCS fleet of each city can be identified when following the trips for more than a year. In this study, we look at the aggregated data at city level, i.e. we do not differentiate between operators or vehicle types. For a comparison between fossil driven and electric driven vehicles see Sprei et al. (2017).

The distance of the trip is not the actual distance travelled but rather the geometric (straight line) distance between the pick-up of the vehicle and the drop-off. The trip duration, besides the actual driving time also includes booking time and time for parking. The utilization rate is calculated by the total time (minutes) all cars are used each day divided by how many minutes they can be potentially driven per day. Average duration and distance of the trips represent usage of these services while the number of trips per vehicle per day and the utilization rate represent the efficiency.

In the next step, histograms are calculated on an hourly basis for workdays in the cities. In the histograms three different type of trips are presented: “short trips”, i.e., trips with a rental time below 15 minutes; “long trips” where the rental time is longer than 15 minutes and the distance of the trip is longer than 1.5 km; “round trips” with a duration of over 15 minutes but a trip distance of less than 1.5 km. For the “round trips” unfortunately we don’t have information about the vehicles’ itinerary.

To look at the most common trips, we divide the city in a grid of 500 meters. The underlying idea is that people are not willing to walk more than 500 meters to reach a car. The gridding will provide us with origin-destination
maps and matrices which show how many trips are taken from each cell (origin) to another cell (destination). These matrices and maps are calculated for different time slots of the day: morning peak, midday, afternoon peak and night. The top ten most frequent trips for each time slot are then presented in a map of the city, illustrating the most common trips taken with free-floating car sharing vehicles during the different times of the day.

The analysis is used to answer the following three questions: First, how do usage pattern variables such as, duration of trips, number of trips per day and utilization rate differ between cities? Second, when during the day are these vehicles used? And, third, where within a city are they most frequently used?

**Results**

**Usage variables to compare cities**

Table 1 presents the usage variables such as average duration and distance of the trips as well as usage efficiency variables such as number of trips per vehicle per day and the utilization rates in percent for the 22 cities studied. Average duration of the trips and the utilization rates are also presented as histograms (see Figure 2 and Figure 3) to show the distribution of the variables between the cities.

<table>
<thead>
<tr>
<th>City</th>
<th>Nr of vehicles</th>
<th>Average duration of trip (min)</th>
<th>Average distance of trip (km)</th>
<th>Nr of trips per vehicle per day</th>
<th>Utilization rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam</td>
<td>614</td>
<td>35.4 (6.2)</td>
<td>3.3 (0.2)</td>
<td>4.6 (1.9)</td>
<td>11.3 (5.2)</td>
</tr>
<tr>
<td>Arlington</td>
<td>96</td>
<td>29.7 (14.4)</td>
<td>2.5 (0.5)</td>
<td>1.9 (0.5)</td>
<td>4.0 (2.2)</td>
</tr>
<tr>
<td>Austin</td>
<td>362</td>
<td>24.6 (1.6)</td>
<td>3.3 (0.2)</td>
<td>3.3 (0.6)</td>
<td>5.7 (1.1)</td>
</tr>
<tr>
<td>Berlin</td>
<td>3774</td>
<td>29.8 (2.0)</td>
<td>4.2 (0.3)</td>
<td>5.3 (0.9)</td>
<td>11.0 (2.2)</td>
</tr>
<tr>
<td>Cologne</td>
<td>703</td>
<td>34.9 (3.0)</td>
<td>4.2 (0.3)</td>
<td>4.5 (0.9)</td>
<td>11.0 (2.6)</td>
</tr>
<tr>
<td>Columbus</td>
<td>199</td>
<td>22.6 (2.2)</td>
<td>2.8 (0.2)</td>
<td>2.6 (0.4)</td>
<td>4.1 (0.8)</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>399</td>
<td>44.6 (9.7)</td>
<td>3.1 (0.3)</td>
<td>2.2 (0.3)</td>
<td>6.8 (1.7)</td>
</tr>
<tr>
<td>Düsseldorf</td>
<td>685</td>
<td>44.2 (6.8)</td>
<td>3.3 (0.2)</td>
<td>3.6 (0.7)</td>
<td>11.1 (2.8)</td>
</tr>
<tr>
<td>Florence</td>
<td>219</td>
<td>26.8 (2.0)</td>
<td>2.9 (0.2)</td>
<td>3.4 (0.5)</td>
<td>6.4 (1.2)</td>
</tr>
<tr>
<td>Frankfurt</td>
<td>597</td>
<td>28.1 (2.2)</td>
<td>3.8 (0.4)</td>
<td>3.1 (0.5)</td>
<td>6.2 (1.2)</td>
</tr>
<tr>
<td>Hamburg</td>
<td>2066</td>
<td>30.2 (3.8)</td>
<td>4.0 (0.2)</td>
<td>5.5 (1.2)</td>
<td>11.7 (2.7)</td>
</tr>
<tr>
<td>Madrid</td>
<td>500</td>
<td>31.9 (2.7)</td>
<td>2.8 (0.1)</td>
<td>9.6 (3.2)</td>
<td>21.6 (7.5)</td>
</tr>
<tr>
<td>Miami</td>
<td>296</td>
<td>29.4 (3.1)</td>
<td>4.0 (0.4)</td>
<td>2.4 (0.3)</td>
<td>4.9 (1.0)</td>
</tr>
<tr>
<td>Montreal</td>
<td>455</td>
<td>29.4 (2.5)</td>
<td>3.0 (0.2)</td>
<td>3.8 (0.6)</td>
<td>7.8 (1.4)</td>
</tr>
<tr>
<td>Munich</td>
<td>1527</td>
<td>32.5 (4.7)</td>
<td>6.0 (1.0)</td>
<td>3.3 (0.8)</td>
<td>7.7 (2.7)</td>
</tr>
<tr>
<td>New York</td>
<td>525</td>
<td>54.9 (17.0)</td>
<td>3.0 (0.4)</td>
<td>3.3 (0.7)</td>
<td>12.2 (3.5)</td>
</tr>
<tr>
<td>Portland</td>
<td>612</td>
<td>25.8 (1.1)</td>
<td>3.3 (0.1)</td>
<td>4.9 (0.7)</td>
<td>8.8 (1.5)</td>
</tr>
<tr>
<td>Stockholm</td>
<td>545</td>
<td>30.2 (3.5)</td>
<td>4.0 (0.9)</td>
<td>2.4 (0.5)</td>
<td>5.0 (1.0)</td>
</tr>
<tr>
<td>Stuttgart</td>
<td>515</td>
<td>35.1 (4.2)</td>
<td>3.8 (0.3)</td>
<td>4.3 (0.9)</td>
<td>10.5 (2.4)</td>
</tr>
<tr>
<td>Toronto</td>
<td>498</td>
<td>38.6 (6.6)</td>
<td>3.3 (0.3)</td>
<td>3.1 (0.6)</td>
<td>8.5 (2.5)</td>
</tr>
<tr>
<td>Washington DC</td>
<td>1011</td>
<td>29.6 (2.9)</td>
<td>3.0 (0.3)</td>
<td>3.6 (0.7)</td>
<td>7.5 (1.7)</td>
</tr>
<tr>
<td>Wien</td>
<td>446</td>
<td>33.7 (2.8)</td>
<td>3.9 (0.2)</td>
<td>4.5 (0.9)</td>
<td>10.5 (2.4)</td>
</tr>
</tbody>
</table>

The utilization rate is calculated by the total time (minutes) all cars are used each day divide by how many minutes they can be potentially driven per day.

We see that Berlin has the highest number of FFCS cars with over 3000 followed by Hamburg and Munich with roughly 2000 and 1500, respectively. It should be noted that FFCS has been present in these cities the longest time and thus the service is more mature here. Arlington has the lowest number of vehicles with 96; however Arlington has merged with Washington with over 1000 vehicles. Columbus Ohio in the US and Florence are two cities with only around 200 vehicles. Florence, however, has other FFCS operators that are not captured in this data implying that for the users there might be more vehicles available in this city.

The average trip duration varies between the cities. For most cities it is roughly half an hour as can be seen in Figure 2. New York has, on average, the longest trips with 54.9 minutes followed by Copenhagen and Düsseldorf with 44.6 and 44.2 minutes respectively. However, standard deviations of the trip durations are quite
high in New York, Arlington and Copenhagen suggesting that the median might be a better measure to compare the cities. Large standard deviation mean that the usage pattern is diverse and that there is a large spread in, in this case, the amount of time the vehicles are booked. The average trip duration is lowest in Columbus which is 22.6 minutes followed by Austin and Portland with 24.6 and 25.8 minutes, respectively.

![Average duration of trip](image)

*Figure 2: Histogram (1-minute interval division) over the average duration of the trips for the 22 cities.*

The average trip distance varies between 2.5 km and 6 km. The longest average trip distances can be found in the German cities of Munich, Berlin, and Cologne with values of 6 km, 4.2 km and 4.2 km respectively. The shortest distances are found in Arlington, Columbus, and Madrid with the distances of 2.5 km, 2.8 km and 2.8 km respectively. For Stockholm and Munich the standard deviations are relatively high. This might warrant further analysis to understand the larger variation of usage in these cities. In the case of Stockholm it might be due to the fact that some trips are within the city, while others are to the airport in Arlanda, located around 40 km outside Stockholm city, which create a larger spread compared to other cities. It should be noted again that the distance of the trip is not the actual distance travelled but rather the geometric straight line distance between the pick-up and the drop-off of the vehicles. Thus, the actual distance travelled might be longer, especially since some of the trips included are round trips (see Figure 4). This is also one of the explanations why the cities with highest average trip duration are not necessarily the ones with the highest average trip distance. Other reasons for this discrepancy might be characteristics of the city and planning, such as type of roads and congestion level, that will affect the average speed of the vehicles.

The number of trips per car per day is the highest in Madrid, Hamburg, and Berlin with 9.5, 5.5 and 5.3 trips respectively, and lowest in Miami, Copenhagen, and Arlington with 1.9, 2.2 and 2.4 trips, respectively. However, the standard deviation is high in Madrid which means that some days these vehicles are used to a larger extent than other days. The number of trips per car per day compares the efficiency of usage of the FFCS services in different cities, and the figures show that these services are more efficiently used in Madrid. These figures can explain some decisions made by the operators, e.g. FFCS operators in Arlington have chosen to merge these with Washington D.C. and Car2Go has discontinued its services in Stockholm, Miami and Copenhagen.

Another measure of the efficiency of usage is the utilization rate. This variable shows the share of minutes in percent that the cars are used each day relative to the time they can be potentially used per day. The utilization rate is highest in Madrid, New York, and Hamburg with the values of 21.6 %, 12.7 % and 11.7 %, respectively. The utilization rate is lowest in Miami, Columbus, and Arlington with the values of 4%, 4.1% and 4.9%, respectively. These three cities are also among the cities with the lowest number of trips per vehicle per day. The standard deviation is high in Madrid and Amsterdam, two cities with only electric vehicles, which shows higher variability in data for utilization rate in these cities. The spread between the cities can be found in Figure 3.
Time distribution of trips

In the next step we look at when during the day the trips are taken. This is done by plotting histograms over the number of trips per hour on average on a workday. In the histograms, the trips are divided into three different categories based on the duration of the trip and the distance between pick-up and drop-off of the vehicle. The dark blue bars in Figure 4 are so called “short trips”, i.e. the rental time is less than 15 minutes. These are a small share of the trips for all the cities. The yellow bars represent the so called “round trips”, i.e. trips that are longer than 15 minutes but have a distance below 1.5 km. These are mainly trips where the user takes the vehicle to some place without checking out and then returns it approximately to the same place that it got picked-up. Unfortunately, we do not have any information relating to where these trips are taken. The majority of the trips are those that are taken for a longer distance than 1.5 km and for a longer time than 15 minutes (green in Figure 4).

Overall the behavior is relatively similar for the different cities and reflects the usage patterns of other transport modes, i.e., there is a morning peak somewhere between 07:00 and 09:00 and a larger and broader peak in the afternoon. Here we choose to present the graphs for six cities to illustrate this. The cities have been chosen for various reasons. Madrid and Berlin represent cities where FFCS is well established with the highest utilization rate (Madrid) and the largest number of vehicles (Berlin). Stockholm and Copenhagen are at the other end with lower number of vehicles and utilization rate. Amsterdam is chosen since together with Madrid it is a city with only electric vehicles in the FFCS fleet. New York is chosen to show a city in the U.S. with high urban density, good public transportation and high utilization rate.

Figure 3. Histogram (1% interval division) showing utilization rate in percentage for the 22 cities.
Figure 4. Histogram of number of trips per hour during weekdays for Madrid, Stockholm, Copenhagen, Berlin, Amsterdam and New York. Divided in “short trips” in dark blue, “long trips” in green and “round trips” in yellow.
Looking specifically at these cities we can see that Madrid differs from the rest of the cities with a peak around lunch time. New York and to a certain extent Berlin, do not have as much of a morning peak. The general usage pattern implies that the vehicles are being used during the normal rush hour. Still, given the small numbers compared to the total number of vehicles on the road they are not a major contributor to congestion today.

Where are the vehicles used? A closer look at Stockholm city

The next step is to identify where the most common trips are taken within a city. This part of the analysis is still in its early stage and we have so far mainly studied Stockholm. Stockholm is chosen since we have a collaboration with the municipality and there was a direct interest in understanding the user patterns here since it is the capital of Sweden, the country where the authors of this paper currently live in. It is also an example of a city with good public transport and where FFCS are in an early phase of establishment. In the future, similar analysis will be done for several other cities as well.

We divide the city into a grid which is based on cells of 500 meters to identify an origin-destination matrix and compute the 10 most frequent trips. This is done for 4 different times of day: morning, midday, evening and night.

![Figure 5. Most common trips in Stockholm during morning, midday, evening and night. Blue is the origin and red is the destination. Round trips are pointed out as purple dots. Each grid is 500 meters x 500 meters.](image)

Figure 5 shows the most common trips in Stockholm during different times of a day. The lines represent the trips. The lines are blue at the starting point of the journey and become red towards the end. As can be seen in the morning, trips are towards the city centre or Solna and Kista which are the areas with a high number of companies and workplaces. Round trips, i.e. the trips that have both origin and destination in one cell, are
represented with a purple dot. These trips are for the times people take the cars to do their errands and come back to the place they started. During the midday, the majority of trips are of this type which is reasonable since people use the lunch time or take some hours off to do their errands. In the evenings and nights, the share of round trips and regular trips are almost the same. As can be seen, the general trend of the direction of the trip at these times is from the centre to the outer sides of the city. Studying the common trips further, one cannot find any Metro or regional train station close to the origin or destination cells of these trips which suggests that these services are used as complement to public transport. However, this is a case study for Stockholm and at this stage we cannot make a general statement about it without further investigation.

Discussion and future work

In this paper, we have looked at the usage patterns for FFCS in different cities in Europe and North America. Our analysis shows different usage patterns between the cities in terms of number of trips per day and per vehicle and the trip length. We find that Madrid, New York and Hamburg have high utilization rates. Berlin is also a city with well-established usage of FFCS with over 3000 vehicles available. Our data also shows that in cities where one of the operators has chosen to discontinue the service, as in Stockholm and Miami, the usage rate is much lower compared to other cities. In the case of Stockholm the other operator is still present.

We also find that the FFCS usage pattern over the day follows most other modes of transport with a smaller morning peak and a larger afternoon peak, with some exceptions such as New York City without morning peak. So far, our analysis is mainly descriptive but we hope to gather further data on the cities to better understand why the services function better in one city compared to another.

Looking more closely at Stockholm we find that in the morning the flow is from the outside of the cities to the centre or major work place districts. During the middle of the day more round-trips are common. In the evening the pattern is reversed to the morning but with slightly more round-trips. From a preliminary analysis, we can see that the most popular origins and destinations are further than 500 meter from a metro or regional train station indicating that these service most probably are used as a complement to public transport.

The data set and the analysis give us a comprehensive view of the movement patterns of these vehicles, i.e. when and to a certain extent where these vehicles are being used. Still, what is lacking from our analysis is the user perspective and the underlying reason. Thus, we cannot with certainty say if these services replace public transport or e.g. personal car use. However, our results for Stockholm show that the most used routes are where public transport is less efficient and thus there is some indication that they are used as a complement to public transport. If this result is generalizable to other cities as well needs further investigation.

FFCS is a new phenomenon and thus it is hard to really evaluate its effect on the transport system in the long run. What are the dynamic effects of having easily accessible motorized transport? Will it make private vehicle ownership less attractive and thus have a large impact on the number of vehicles available or will it increase motorized transport for people who anyway would have given up their own vehicle or would travel by public transport instead? In the long run the competition with other service such as Uber and Lyft, especially if paired with autonomous vehicles, might make FFCS less attractive. Another alternative is that there will be increased blurring between the modes. Already there are indications that in the U.S. FFCS vehicles can be used for ride hailing service as well. Further studies will be needed to better understand these dynamics, where current usage patterns can form a starting point to understand the possible impact.

Future work includes continuous work on the database, looking more closely into more cities as well as comparing origin-destination travel times with other modes such as biking, walking and public transport, as well as the impact of weather. Data on city characteristics that might explain the differences between the cities is also being gathered. Ideally this data would be combined with user surveys and in depth user-studies to better understand the motives behind the transportation choice.

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