What about free-floating carsharing?
A look at the Montreal case

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ABSTRACT

In recent years carsharing has become a practical, ecological, and economical alternative to private car ownership all around the world. Traditional carsharing is station-based, but recently new types of shared services have appeared, and one of these is free-floating carsharing. It is more flexible, but what is its impact on user behavior? This paper aims to characterize the use of the free-floating carsharing service in central Montreal (Canada). We compare the use of the traditional, station-based service and the new service. Some people are members of both services, so we are able to examine the specific contribution of each service to meeting travel needs. We also explore the impact of the introduction of this new transportation alternative. The results show that, compared with traditional carsharing, more women are members of the free-floating service, and the trip distances and durations are much shorter. Shopping is the most important activity, and there is a concentration of trip ends near the central business district in the midday period. When asked what mode they would have used in the absence of the free-floating service, the users mentioned public transit, taxis, and walking; the popularity of these alternatives varies, probably in relation to seasonal changes. Further studies are required to measure the environmental impact of this new transportation mode.

Key words: Carsharing, free-floating, travel behavior, reservation log, GPS data.

INTRODUCTION

Carsharing is a practical, ecological, and economical alternative to private car ownership. Station-based carsharing is increasingly popular, and the recently introduced free-floating carsharing provides more flexibility. The latter allows members to borrow a car from the street and return it anywhere in the service zone; it is hence a one-way system that is not based on stations. The extra flexibility seems to be beneficial for users, but little is known about the role it plays in urban areas. We need to better understand the travel behavior related to this new mode before investigating its social and environmental impact. We also need to assess the differences between traditional and free-floating services. This paper explores these questions.

We aim to compare the attributes of the members, reservations, and trips of traditional and free-floating carsharing services in the Montreal area. In particular, we will study the differences of both services from individuals who attend both services. Our study is based on four datasets providing transactional data for both services, GPS traces for the free-floating cars, and a targeted survey designed to provide a better understanding of the use of the new service.

We first present a literature review that defines the different carsharing services, discusses recent studies of the travel behavior of carshare members, and synthesizes studies on one-way carsharing. The methodology section describes the case study, discusses the datasets, and explains the survey. It also presents the methods used to format the datasets, process the GPS traces, and determine the member type. The results are divided into three parts. We present a comparison of traditional and free-floating services, we discuss the characteristics of the free-floating trips, and we use the survey responses to give an in-depth analysis of the use of the free-floating service. The conclusion summarizes the main results and discusses future research.

BACKGROUND

In this section we present empirical research into carsharing. We define the three types of carsharing systems, describe work that explores the user travel behavior, and discuss research into free-floating carsharing.

Definitions

There is no universally accepted definition of carsharing. Millard-Ball et al. *(1)* present the administrative definitions used by various organizations; these definitions vary but have common features. Carsharing can be defined as a practice where multiple people in a profit or nonprofit organization share the use of multiple vehicles in exchange for a fee. The fee may include a membership charge, a variable rate, and a fixed rate; it is based on actual usage.

We discuss three types of carsharing: station-based, one-way, and free-floating. Station-based carsharing is also referred to as two-way (round-trip) or traditional carsharing. The users have access to cars distributed among stations in the network. A user must make a reservation prior to the trip for a car at a specific station and must return the vehicle to the same station *(2)*. An example of this service is Communauto, in Montreal. In contrast, one-way and free-floating carsharing allow users to return the vehicle to a location that differs from the one where it was borrowed, making one-way trips possible *(3)*. The definitions of these two services vary. Firnkorn *(4)* defines free-floating as a scheme where no fixed station is present on the network or no a priori booking is needed *(5)*. For Schaefers *(6)* free-floating means that the user simply returns the car to any public parking space inside a specific operating area. Jorge et al. *(2)* define one-way carsharing as a scheme where the user collects the car at a station and returns it to the station of his choice. In this paper, one-way carsharing will refer to one-way trips where the cars are collected from and returned to stations. Free-floating carsharing will refer to one-way trips where the cars are collected from and returned to any location in a service area. The service of Autolib in France is an example of one-way carsharing, and the service of Car2Go in Montreal, Austin, and other major cities is an example of free-floating carsharing.

Travel behavior of carshare members

The user behavior for station-based carsharing has been studied previously *(7,8,9)*. Morency, Trépanier, and Agard *(10)* used data-mining techniques to develop a typology based on the frequency of use (the number of transactions) and the distance traveled. They found two main groups of users, high-frequency (HF) users (14%) and low-frequency (LF) users (86%). The HF users made on average 5.5 times more transactions than the LF users. In terms of the distance traveled, they found that almost half of the users had behavior that varied over time, and the rest had stable behavior for either long distances (17% of the members) or short distances (33%). Leclerc *(11)* studied the travel behavior of users by processing their GPS coordinates. He investigated the transactions by splitting them into trips, determining stops (activity locations), and assigning attributes of the users to individual trips. He analyzed both full trip chains and individual trips. He found that the users tend to make short trips that are not related to their work and to maximize the use of the car *(12)*. Costain et al. *(13)* studied a broader range of dimensions of user behavior. They studied the users' attitude to the environment, safety, frequency of use, duration, and vehicle type using a transactional dataset from AutoShare, a Toronto station-based carsharing organization.

One-way carsharing

A few researchers have investigated one-way and free-floating carsharing. The environmental impact of station-based carsharing has been studied *(14,15,16)*. Firnkorn and Müller *(5)* discussed the environmental impact of free-floating carsharing using survey results from Car2Go users. They determined three possible outcomes in terms of CO_2 emissions, and all three reduced these emissions. Station-based carsharing leads to a reduction in car ownership *(17,18,19,20)*. Firnkorn and Müller *(5)* carried out a survey to investigate the impact of free-floating carsharing on the users' car ownership. Agent-based simulations are sometimes used to simulate user behavior *(21,22,23)*. Ciari et al. *(24)* used multi-agent simulation for the demand modeling of free-floating carsharing in comparison to station-based carsharing. Using MATSim, they modeled three main scenarios: station-based carsharing, station-based carsharing with larger stations, and a combination of station-based and free-floating carsharing. The free-floating service seemed to be complementary to the existing station-based service; the trips were shorter and occurred at different times of the day. Other studies focused on relocation strategies for free-floating carsharing *(25)*; the lack of fixed stations makes this a complex issue. Schaefers *(6)* explored users' motivations for joining a free-floating carsharing service using a hierarchical value map (HVM) to represent the different associations.

To date there is no complete study of travel behavior in a carsharing service offering both station-based and free-floating options. We try to explain free-floating travel behavior using quantitative data (a dataset of carshare transactions) along with some qualitative data (a survey), and we compare this behavior with the usage pattern of the traditional service for the same users.

METHODOLOGY

Case study

This research is conducted in collaboration with one of the largest carsharing providers in North America, Communauto (about 1,500 cars and 28,000 members). Communauto provides a regular service (REG) based on 450 stations. On June 16th 2013, the company added a new free-floating carsharing service called "Auto-mobile" (AuM) *(26)*. The service zone is in central Montreal (shown in Figure 1).

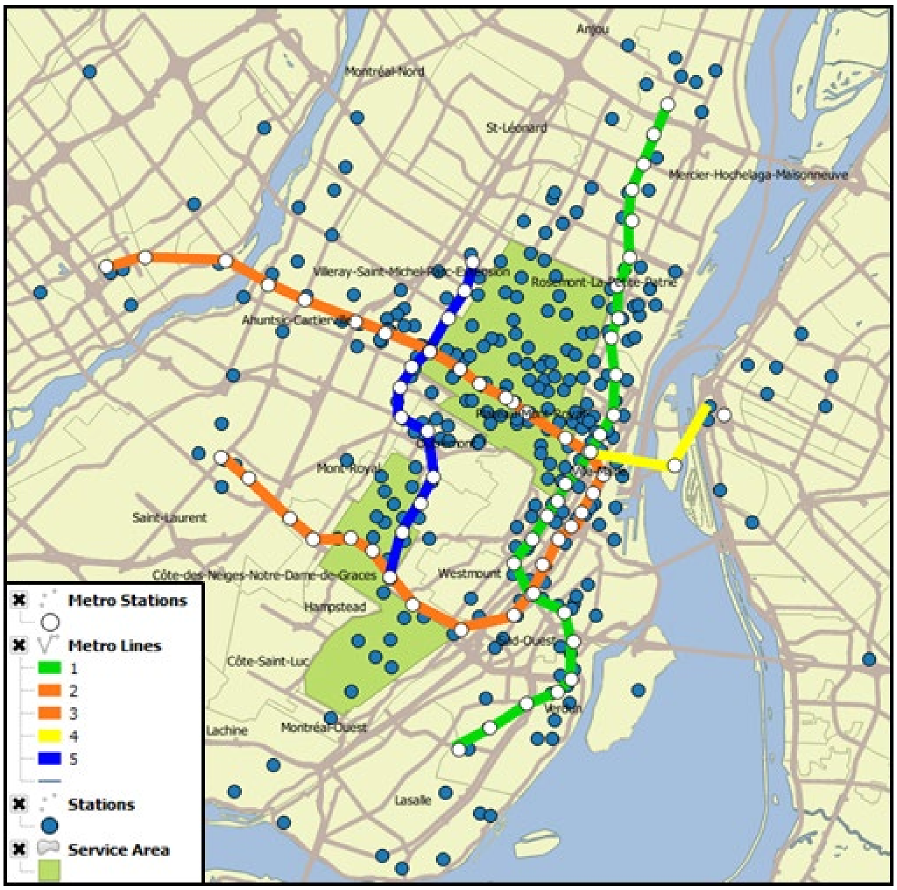

Figure 1: Communauto AuM service area and REG stations (March 2014)

Pricing Scheme

The AuM and REG pricing schemes are different. There is no $500 refundable membership fee for AuM (although the REG service offers one package without a membership fee). Moreover, the annual fees for REG typically range from $40 to $360/year; there is no annual fee for AuM. Also, the variable rate for AuM is based on duration ($0.38/minute) and not trip length (but if a user exceeds 100 km, there is an extra charge of $0.20/km). REG has many different package variations, but the basic ones offer a per-kilometer rate between $0.16 and $0.40 and an hourly rate between $1.70 and $5.20. Gas and insurance are included for both services.

Information system

Communauto has made multiple datasets available for the purpose of this research:

1. **Transactions and GPS traces of Auto-mobile usage (AuM).** A total of 22,993 transactions were registered from June 30th 2013 to March 4th 2014. The GPS traces contain 2,087,782 geographical coordinates. The transaction information provides the customer ID (anonymous), date and time of use, vehicle ID, distance, duration, and transaction coordinates.
2. **Communauto regular database (REG).** This dataset contains records for the reservations of the regular carsharing service: member details, vehicle records, and station information. There were 1,572,076 reservations from January 1st 2013 to March 5th 2014 involving 40,558 registered members, 1,410 active cars, and 440 stations. The transaction information provides the customer ID (anonymous but with gender, age, postal code of residence), date, time of use, duration, distance traveled, station, and vehicle ID.
3. **Survey of Auto-mobile user behavior.** Following their use of an Auto-mobile car, members were asked to complete a seven-question survey about the trip. Overall, 1,174 responses were collected from September 6th 2013 to February 4th 2014. We discuss the survey later.

We can combine the data in various ways. The AuM usage can be combined with user data to obtain more information about the member characteristics. It can also be combined with the survey data, so information such as the activity and the preferred alternative mode can be acquired. The GPS data is used to characterize each AuM trip. One of the challenges that we faced was the merging of these heterogeneous datasets, which is discussed in the section on the "Data processing method" below.

The study period (June 2013 to March 2014) has some limitations. Travel behavior may change over the course of a year, especially in Montreal where the seasonal weather changes are extreme. Vacation times and work patterns can also affect the travel behavior. Moreover, during the study period, AuM was in constant expansion; this could have affected the results.

Data processing method

The three datasets had different file formats. We integrated them into a single database management system (DBMS) so that we could manipulate the information and execute queries. We cleaned the data, retaining only the active users (40,558 of 73,287). Of the 22,993 AuM transactions, 2,084 were relocations performed by Communauto employees, giving a total of 20,908 eligible transactions and 2,001,373 GPS coordinates. For the REG service, the user trips were recorded as reservations. The data included canceled reservations, employee trips, and nonoverlapping periods of time. After we filtered the irrelevant data, 697,801 reservations remained. To allow us to compare AuM and REG, we will analyze only the data covering June 30th 2013 to March 4th 2014: a total of 382,623 REG reservations.

Survey

The survey was in the form of an email sent to all users of the AuM service. The following questions are relevant to our study:

- Q4: What is the purpose of the trip? (Work, school, grocery/shopping, medical, visiting a friend, returning home, taking someone home)
- Q5: If Auto-mobile had not been available, what transportation mode would you have used for this trip? (I wouldn't have done the trip, regular carsharing, public transit, taxi, personal bike, personal car, walking, bikesharing)

The survey responses are not necessarily linked to an AuM transaction; only the user ID and the day of the transaction are available. The link between the survey responses and the transactions is based on the honesty of the respondents and on basic validation. First, we combine all the transactions of a particular user recorded within an interval of 60 min (during AuM trips, members can release the car and then borrow it again, and this counts as two transactions). The risk of combining two unrelated transactions is small. Second, if there is more than one match for a given survey response, we reject the response.

GPS trace processing

The processing of the GPS data for AuM trips is not straightforward because there can be discrepancies between the traces, which give the location of the car over time, and the actual trips taken by members. We need sufficient movement of the car to retrieve the GPS trace, so we retained only transactions that presented a "reservation part" or covered a distance of at least 200 m. We developed an algorithm to determine these trips; it found a total of 14,692 transactions. From these 14,692 transactions, we generated 24,995 trips and 12,039 stops. More than one trip can be made during a reservation, although this is a one-way service, because a member can park a car for a short period without releasing it or make a trip out of the service zone (which necessitates a return trip). The status of each car is one of the following:

- Available: the car is available and can be used by anyone.
- Reserved, awaiting client: a user has reserved the car for a 10-minute period.
- Reserved, en route: the user has taken possession of the car, and the car is on the road.
- Reserved, end requested: the user is ready to terminate the transaction. The car will now be available to anyone.
- Reserved, awaiting client return: the client has parked the car but has not completed the transaction. The car is still reserved, and the client must pay for the waiting time.

Customer type identification

In the Communauto system, members may use both the AuM and the REG service. We classify the customers into four groups. We first identify through which service (AuM or REG) the customer has entered Communauto's system. We then identify whether or not the customer has used the other service. The distribution is quite uneven:

- 38,917 REG–REG members (REG members who have never used AuM);
- 610 AuM–AuM members (members who use AuM exclusively);
- 988 REG–AuM members (REG members first who have tried AuM afterward);
- 43 AuM–REG members (AuM members first who have tried REG afterward);

The last two categories of hybrid users will allow us to explore how behavior differs between the services.

RESULTS

Comparison of free floating (AuM) and station-based (REG) carsharing

We first consider the membership. Figure 2 shows the demographic breakdown; active clients who have made at least one trip in the study period are included.

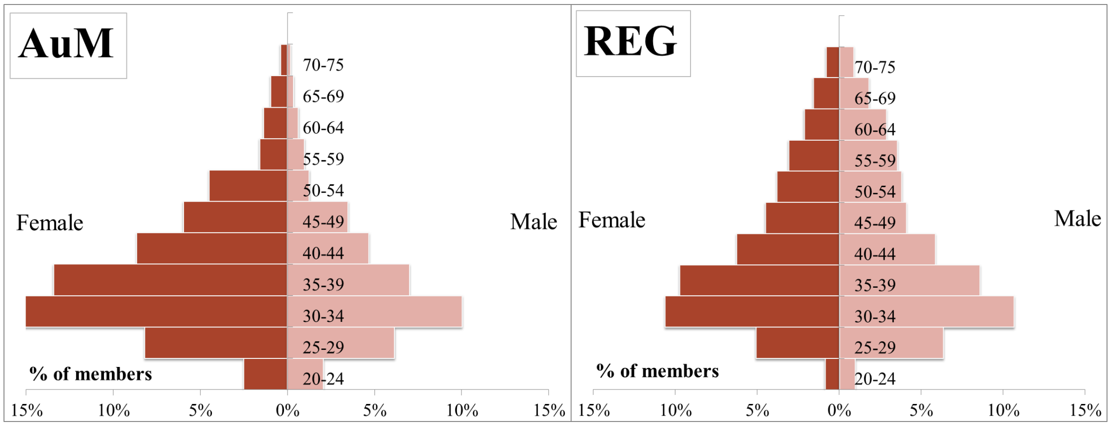

Figure 2: Age pyramid of AuM and REG membership

REG has an even distribution of men and women with a 49/51 ratio, but 63.3% of the AuM customers are women, a significant difference. Both types of customers are fairly young, but AuM customers are slightly younger than REG customers. For REG the 25–49 age bracket has 71.1% of the users; for AuM the 25–44 age bracket has 73.8% of the users. The average ages are 41.4 ± 12.3 for REG and 37.6 ± 9.7 for AuM, with median values of 38 and 35.

A comparison of AuM and REG carsharing is not straightforward. The metrics (trips, transactions, and reservations) are not totally equivalent. Reservations are the metric for REG, and transactions are the metric for AuM. Reservations are essentially full trip chains, starting and ending at the same point. Transactions may represent a full tripchain or be open-ended.

In terms of distance, 80.5% of the AuM transactions and only 20.9% of the REG reservations are less than 10 km, revealing a significant difference. REG trips are mostly in the 5–20 km range (41.1%), with a widespread distribution, while AuM transactions fluctuate around 0–6 km (68.5%) with a more saturated distribution. For AuM, the average distance is 8.5 km and the median value is 3.8 km; the figures for REG are 50.9 km and 23.0 km. The REG reservations were broken into individual segments by Leclerc *(11)*, who found that a segment is 8.1 km long on average (with a standard deviation of 23.7 km).

Similar observations apply to the duration of REG and AuM trips: 92.3% of the AuM trips but only 42.4% of the REG trips were completed within three hours. The AuM transaction duration distribution is heavily concentrated below 1 hour of use (81.2%), whereas REG reservations range from 0 to 7 hours (75.9%). The average AuM duration is 97.2 min with a median of 17.3 min; the figures for REG are 437.6 min and 240.0 min. Leclerc *(11)* stated that the average REG segment is 56.2 min. Clearly, AuM and REG have different usage patterns.

Figure 3 presents the start time of AuM transactions and REG reservations by the time of the day and broken down by weekday/weekend. For AuM, the use of the service is higher on weekends than on weekdays. Saturday and Sunday account for 34.1% of all transactions (17.1% per day), while weekdays represent 65.9% (13.8% per day). On weekends, the peak period is from 11 a.m. to 5 p.m. (54.4% of the weekends). On weekdays, we observe three peak periods, one from 7 a.m. to 9 a.m. (14.8%), one during the lunch period (15.4%), and an important one from 4 p.m. to 7 p.m. (33.5%). For REG, the average weekend day has 15.6% of the weekly reservations, and the average weekday has 13.8%. The weekend peak for REG is earlier (8 a.m. to 11 a.m.; 42.1%); this is because REG reservations are longer than AuM transactions. An AuM user may end a transaction and start another an hour later, whereas a REG reservation does not end until the car is returned to the station, so there are fewer "new transactions" in the system. The weekday peak for REG is similar to the AuM peak, but with a smaller difference between the morning (23.6%) and the afternoon (30.2%). The daily usage patterns show that people use AuM at night: the period from 9 p.m. to 2 a.m. represents 14.2% of the transactions. At this time AuM is a good alternative to other transportation modes such as public transit, which offer a less frequent service at night.

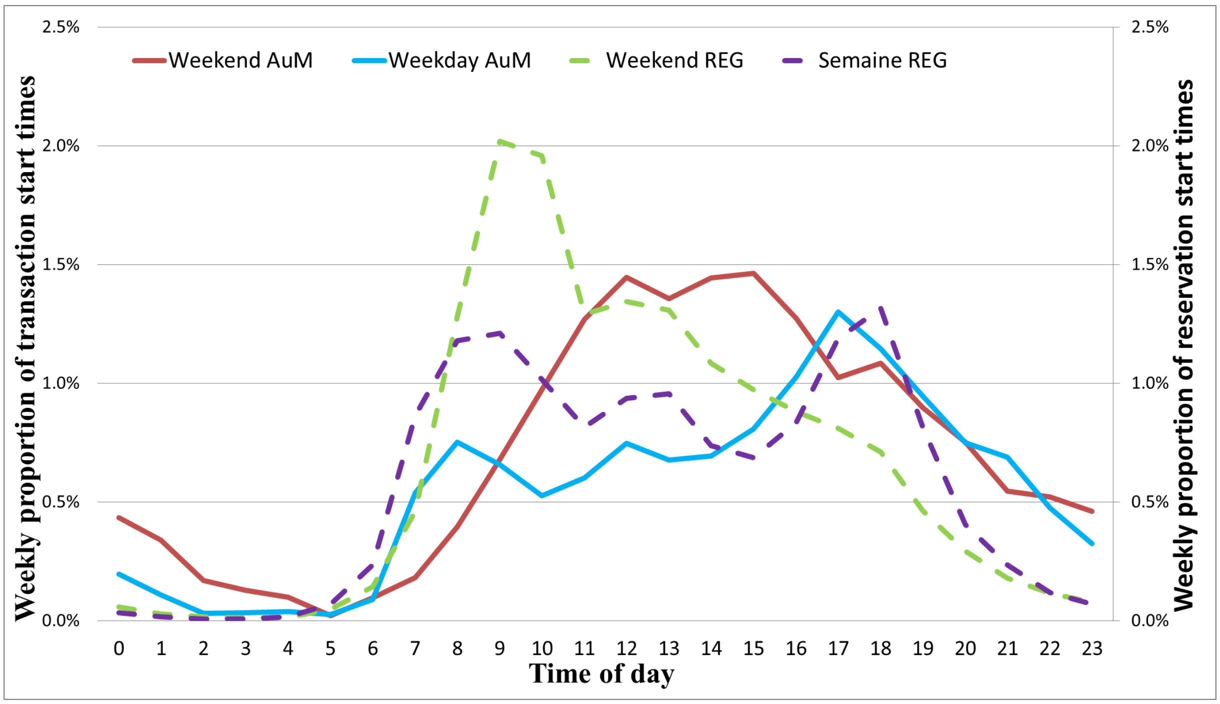

Figure 3: AM and REG use by time of day, for weekdays and weekends

Characteristics of AuM (free-floating) trips

In this section, we define user-weeks where members are assigned to one or more types based on their weekly reservations. This methodology is used to analyze the duration and distance for AuM trips (therefore, the REG–REG group is not present).

The first observation on the duration is that the members who have tried REG have shorter transactions than those who have not. The median transaction durations for AuM–AuM, AuM–REG, and REG–AuM users are respectively 20.7 min, 14.6 min, and 15.3 min. The transactions for AuM–AuM are 35.3% to 41.8% longer than those for REG–AuM and AuM–REG. REG users may use AuM for shorter trips and REG for longer trips. The second observation is that, for all three customer groups, transactions over the holiday period are much longer than those for the other periods studied.

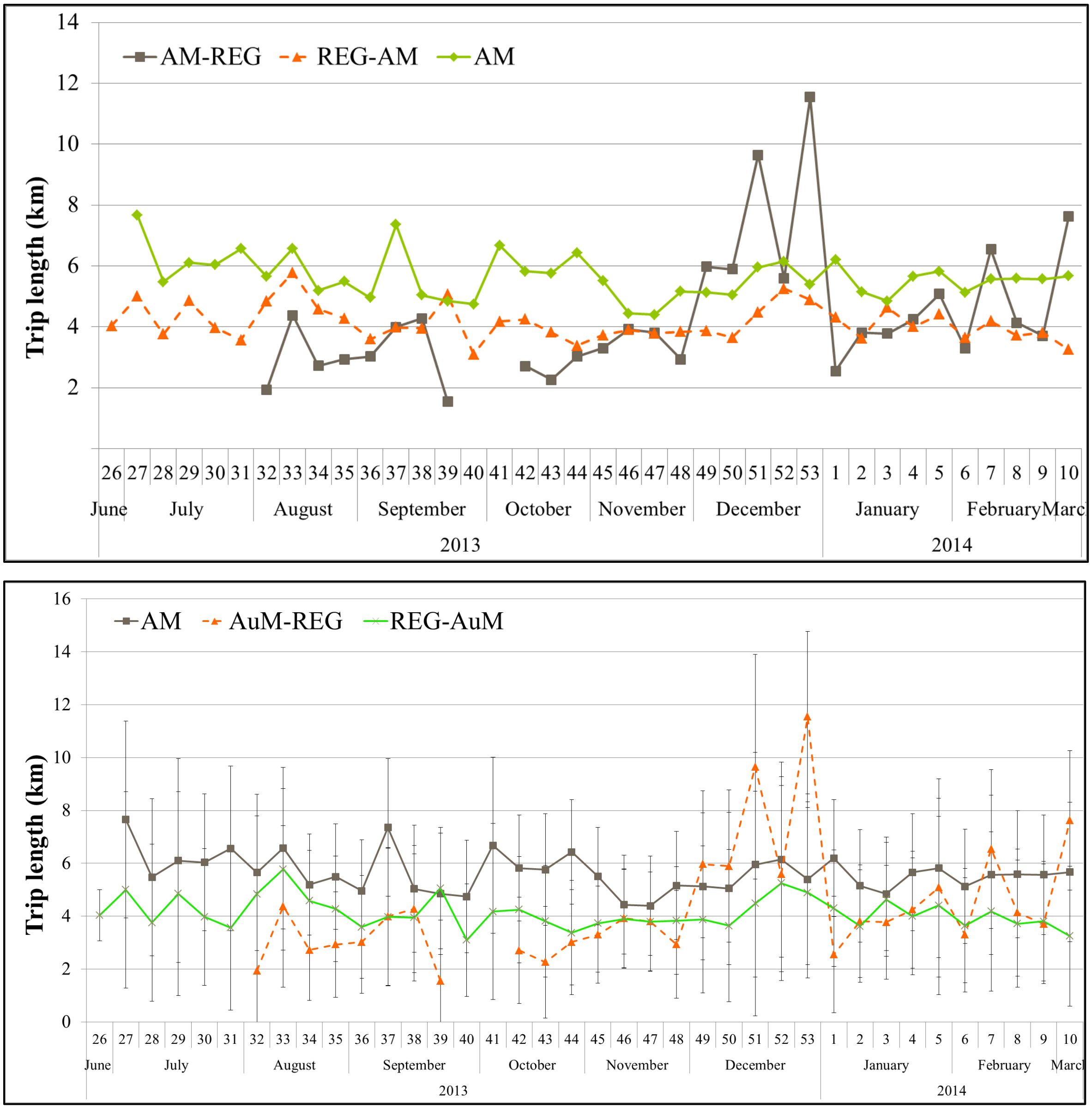

Figure 3: Average length of trips by member type

Figure 4 presents the average AuM trip length by group for each week. AuM trips are around 2.0 km to 8.0 km on average in a non-holiday period. From mid- to end-December, the trip length increases significantly. On average, for weeks 51 to 53, the mean distances are 7.5 km, 9.1 km, and 5.7 km for the AuM, AuM–REG, and REG–AuM groups. For the other weeks, the mean distances are 6.8 km, 4.2 km, and 4.1 km respectively. The overall median distances are 3.4 km, 3.2 km, and 2.7 km respectively. We compared the mean distances using a statistical test. At the 95% confidence level, there is a significant difference between the REG–AuM trips and the AuM trips (confidence interval: [1.227 km, 1.526 km]) and between the AuM–REG trips and the AuM trips (confidence interval: [0.644 km, 1.508 km]). There is no significant difference between the REG–AuM trips and the AuM–REG trips.

Figure 5 shows the spatial distribution of the AuM trips in the Rosemont-La-Petite-Patrie and Plateau-Mont-Royal districts. We count all the trips starting inside the 250 m x 250 m grid. Most of the trips are done during the midday period. During this period, many trips start in the south of the zone, which is closest to the central business district. The trips of the entire dataset are represented.

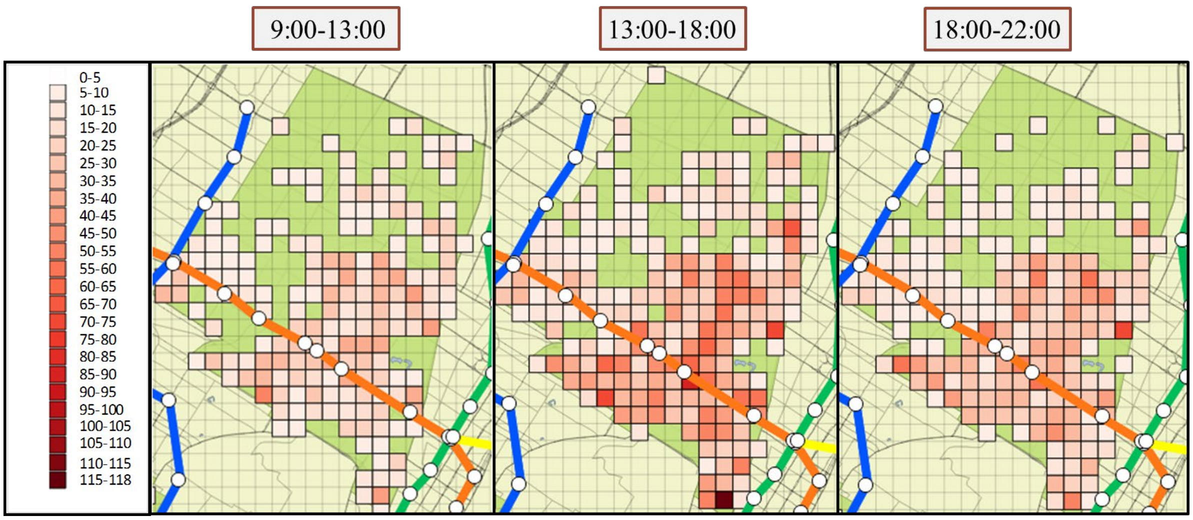

Figure 4: AuM trip origin density map by time of day, 250 m x 250 m grid

In-depth analysis of survey responses

In this section we analyze the survey responses and compare them to the actual behavior of the members. The main AuM activity, according to the survey, is shopping (400 responses; 34.1%). In second place are visiting a friend and returning home (211 and 210 responses respectively; 18.0% each). AuM is popular for shopping because it is convenient to have a car to bring home the goods purchased. The high volume of AuM responses is normal given the nature of the service. The above activities are relatively unconstrained, in contrast to work, school, or medical appointments, for which the schedule is usually known in advance. This may explain the popularity of AuM for these trips: a spontaneous service with a pricing structure that promotes shorter trips is both appealing and appropriate. There are no significant differences between men and women.

We successfully matched 850 survey responses to AuM trips. Figure 6 shows the median distance of trips and the median duration of stops by activity.

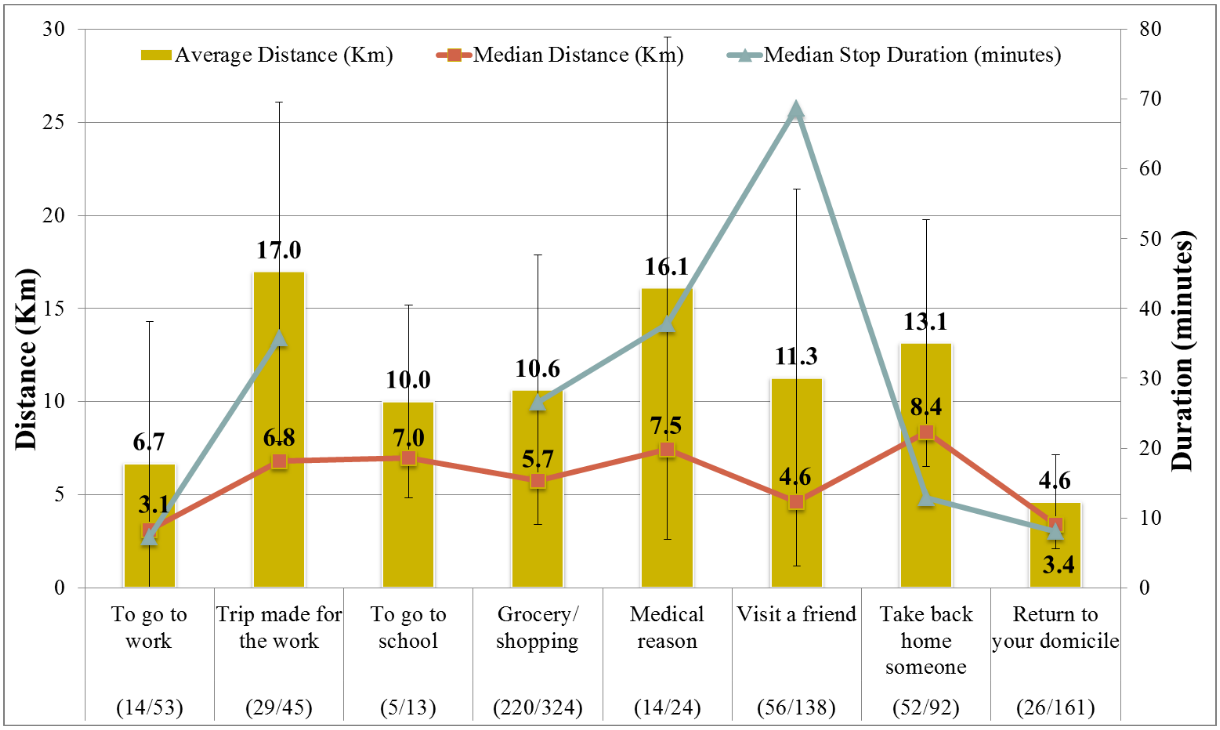

Figure 5: Activity from AuM survey, showing average and median trip distance (km) and stop time (min); the ratios in parentheses are the number of stops (total of 416) over the number of trips (total of 850)

The activities returning home (3.4 km), going to work (3.1 km), and visiting a friend (4.6 km) are shorter than the other activities. Returning home and going to work are one-way activities. Most of the users live inside the service area, and a user making a one-way trip wants to leave the vehicle at his arrival location (inside the service area), so these trips are naturally shorter. The activities bringing someone home (8.4 km) and attending a medical appointment (7.5 km) are the longest.

We also studied the stop time for users where applicable. For one-way trips (to work, to home), the stop time is short: 7.3 min and 8.0 min respectively. A visit to a friend includes time spent with him/her. The responses show that this category has the highest median value: 68.7 min. The other categories have a median stop time of between 25 and 40 min.

We next investigated the transportation mode being replaced by the AuM trip (Figure 7). From September 9th to November 15th 2013, the Bixi bikesharing system was operating (it was then removed for the winter). The main transportation mode replaced by AuM is public transit (23.7%), and the second is REG. Active transportation modes such as Bixi, walking, and personal bike total 26.4%. About 18.4% of the trips would not have been made without AuM. After mid-November, the share of public transit increases significantly, to 38.7%, and the active transportation share decreases to 19.9%. Weather is the main factor here, while other transport modes such as REG, personal car, and someone else's car seem to be independent of the weather.

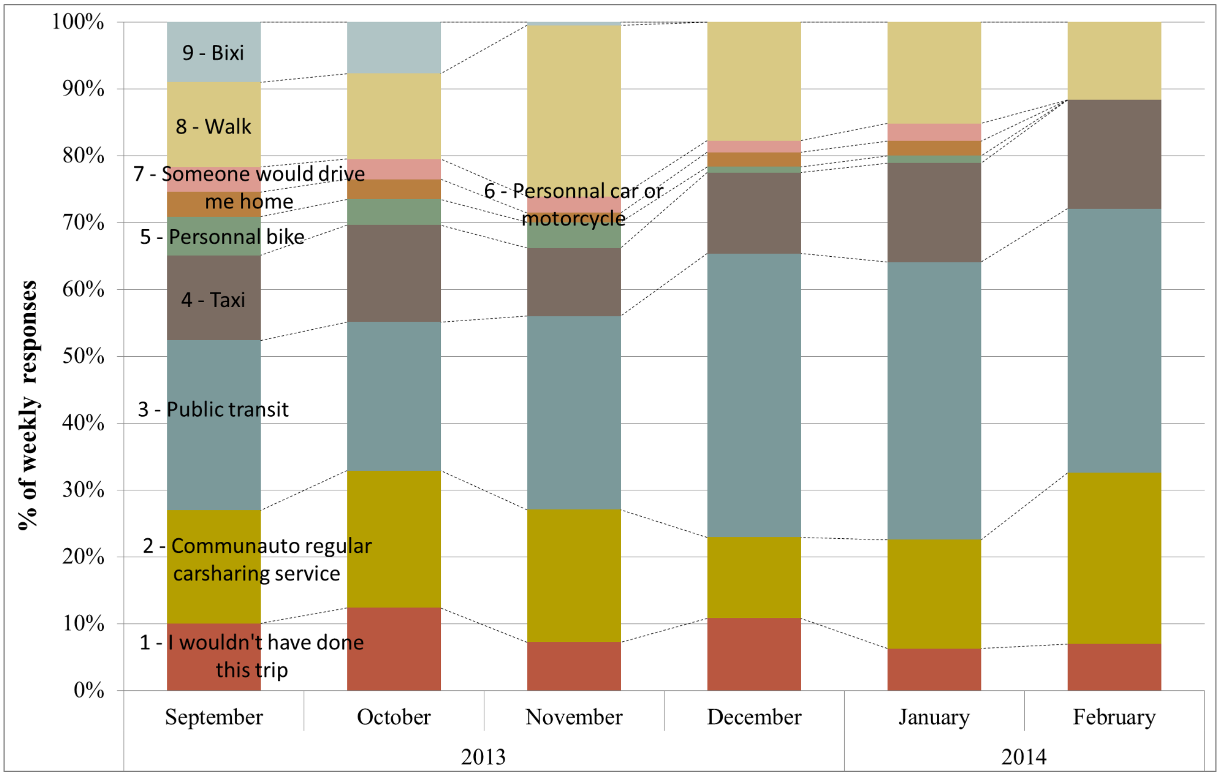

Figure 6: Mode replaced by the AuM trip, by month

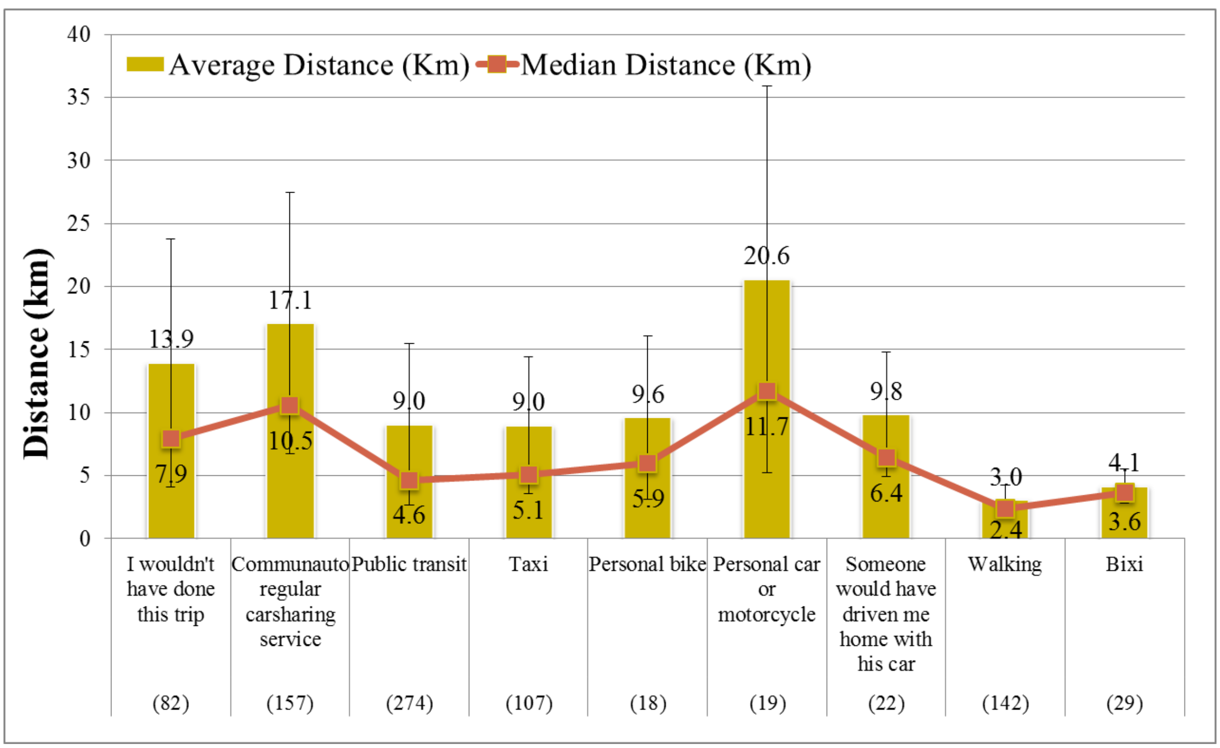

Figure 7: AuM trip by replaced mode, showing average and median trip length (km); the figures in parentheses are the number of occurrences (total of 850)

Figure 8 shows the characteristics of the AuM trips according to the mode replaced. Surprisingly, the results concur well with the observed behavior. Users who indicated active transportation modes (walking, biking, Bixi) have made relatively short trips (2.4 km, 5.9 km, 3.6 km). The personal bike does not have the station constraints of Bixi, so the traveled distance is much greater. Trips involving cars were the longest: 11.7 km for personal car, 10.5 km for REG, and 6.4 km for someone else's car.

CONCLUSION

This paper has presented a comprehensive study of free-floating carsharing travel behavior in the Montreal area. We achieved this by combining a dataset of the AuM transactions with survey responses. We used a REG dataset to compare the two services. It is clear that the two services have different usage patterns, and therefore they should be treated separately in future studies. However, our study has some limitations. First, it would be interesting to develop an external validation method to better link the survey responses to the transactional data. Second, the GPS trace analysis needs enhancement and exogenous validation.

A deeper study on the complementary of the free-floating carsharing service with other transportation modes, like public transit, taxi, and other shared or active alternatives would allow to better understand the market for such service within urban transportation systems, and develop comprehensive mode choice models for various types of users. Furthermore, the environment impact and the impact on vehicle ownership should be studied to determine to what extent free-floating carsharing can be considered a sustainable mode of transportation.

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