Understanding the factors affecting vehicle usage and availability in carsharing networks: A case study of Communauto carsharing system from Montréal, Canada

Alexandre de Lorimier
Consultant, Special Projects
Quartier international de Montréal
Centre de commerce mondial
Suite 3220, 380 Saint-Antoine Street West
Montréal, Québec H2Y 3X7
Canada
Tel.: +1 514 841-7634
Fax: +1 514 841-7776
Email: adelorimier@qimtl.qc.ca

Ahmed M. El-Geneidy (corresponding author)
Assistant Professor
School of Urban Planning
McGill University
Suite 400, 815 Sherbrooke Street West
Montréal, Québec H3A 2K6
Canada
Tel.: +1 514 398-4075
Fax: +1 514 398-8376
Email: ahmed.elgeneidy@mcgill.ca

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ABSTRACT

The novelty of carsharing as an alternative to private car in dense urban areas raises a number of questions regarding the logistics of operating a carsharing network. Subscribers of carsharing networks have been growing at a fast rate in recent years. This increase was accompanied by more complex problems due to changes in the demand and shortages in supply. This study seeks to determine the factors affecting vehicle usage and availability in the Communauto carsharing network in Montréal, Québec. Using data provided by the carsharing operator, a multilevel regression model focussing on vehicle usage and a logistic regression model focussing on vehicle availability were devised. The study determined that a number of factors have a major impact on either availability or usage. The number of vehicles parked at a station has the most effect on availability, with a great variation during the seasons. Vehicle usage is affected by average vehicle age, and by member concentration in the vicinity of the station. The findings from this research can be beneficial to transportation planners and engineers working with carsharing operators to build or expand their network.

Keywords: Carsharing, Private car, Road transport, Sustainability, Transport policy, Urban transport

INTRODUCTION

The private automobile has had a massive impact on the way we build and design our cities. Urban areas are based on quick and efficient individual mobility. Our roads are engineered to ensure a smooth flow of people and goods, and give motor vehicles a prominent role in society. Alternatives to the private vehicle are numerous, but they serve very different purposes. Public transit is useful for short trips within the city in dense areas that can sustain the high ridership required to make a bus, tram or métro network financially viable. Active modes of transportation such as walking or cycling are increasingly popular in cities as well. Not only are they healthy breaks for short trips but they also reduce our collective and individual carbon footprints. However, these modes are ill-adapted for families, and cannot be used to carry the goods that are paramount to our consumer economies.

The methods of travel described above are different transportation modes. Carsharing, however, is not a mode per se, but rather a major shift in the ownership and usage structure of individual cars. In fact, the private car remains the vehicle of choice within a carsharing system; it is how drivers use this car that makes the difference. In a carsharing system, users choose to subscribe to a service that will give them access to a fleet of vehicles for short trips within—or in close proximity to—an urban area. The member can then make one or more trips as long as the car is used during a pre-set booking period. In this fashion, individuals can take advantage of all the benefits of a private vehicle without the hassles of lease payments, maintenance or parking. In dense urban areas, where fewer trips require a private vehicle, this is an ideal complement to the assortment of transportation options already available. Furthermore, carsharing reduces the number of cars on the road by making the purchase of a new vehicle unnecessary. Inspired by the model's appeal, efficiency and versatility, it is our belief that carsharing along with public and active modes of transportation are key elements to a new urban transportation paradigm.

The value of carsharing was realized by many transportation agencies, which has lead to a rapid increase in the number of carsharing programs around the world. Carsharing provides an option to many people who choose not to own a vehicle, and instead use these systems when a private vehicle is needed. The number of members in carsharing networks has been growing at a very fast rate as well in the last few years. This increase was accompanied by more complex challenges to carsharing operators due to changes in the demand and limitations in supply. The majority of carsharing companies are not subsidised and increasing fleet size, as well as acquiring new stations to meet demand, are complex matters and require large capital investments. This study seeks to determine factors affecting vehicle usage and availability in the Communauto carsharing network in Montréal, Québec, with goal of prioritizing investments in areas that will have the highest benefits to the existing members and the carsharing operator. Findings from this research can be beneficial to transportation planners and engineers working with carsharing operators to build or expand their network. This study will also help to better understand demand characteristics for carsharing in a North American context.

This research paper begins with a literature review, which outlines the history behind carsharing and previous studies on the topic. We then introduce the Communauto carsharing network before describing the data sources and methods employed in the study. The next section presents the results of the study through an in-depth analysis of statistical models. Finally, we conclude with a number of recommendations that can be applicable to any carsharing agency.

LITERATURE REVIEW

Early adopters of carsharing

Any innovation requires early adopters, persons who are willing to take the first leap of faith and embrace a new technology or a new service. In 1994, Meijkamp & Theunissen *(1)* conducted a study of early carsharing users in The Netherlands. Carsharing was only starting to become a successful commercial venture. They studied a group of people who chose to become members of the Huur-op-Maat program in the city of Leiden. They organised focus group sessions with 10 clients of the carsharing organization (CSO). They determined that how one comes to adopt carsharing as a mode of transportation is key, and that policies must encourage carsharing in order to make the model more popular.

Early adopters were found to be critical during the early stages of North American carsharing development. In 1999, Katzev *(2)* analysed the adoption process of new Car Sharing Portland (CSP) members. He found that early adopters of carsharing in Portland were highly educated, relatively affluent group of individuals. He also noted that while participants were conscious of environmental issues, it was not their primary reason for joining the CSO. These findings confirmed the same trends described in earlier European studies, a survey of 262 PhillyCarShare early adopters in 2003 and trends elsewhere in the US *(3)*. The PhillyCarShare study established that income was not a major determinant in being a carsharing user; however, low income groups were likely less represented because of the initial costs of joining a CSO such as large security deposits and credit checks. Convenience and affordability were cited as the main reasons for members to join. Convenience is cited only when a member tries to reserve a car and he succeeds. The high percentage of failure in reserving a car is expected to lead to a decline in carsharing members.

Effects of carsharing on personal mobility

The effects of carsharing on personal mobility have been researched often during the last ten years. We will focus on North American studies since operating conditions are quite different in Europe and research methods have not yet been standardised. In fact, this creates some issues when comparing data from different CSOs; the formulation of questions in surveys, the use of non-verified vehicle-miles-traveled (VMT) figures given by members and other methodological differences generates variance between studies *(4)*.

One major impact of carsharing is its effect on car ownership. As a general rule, carsharing tends to reduce the need for a private car by replacing a personal vehicle with a shared one. In Philadelphia, Lane *(3)* determined that each PhillyCarShare vehicle contributed to the removal of 22.8 cars on average from roads. In other words, 10.8 cars are removed by members who gave up an existing vehicle and 12.0 cars are removed by members who decided not to purchase a new vehicle. Millard-Ball *(5)* compiled car ownership information from previous studies and estimated that car sharing removes 14.9 private cars from the road. A 2006 report for the Communauto CSO in Montréal determined that each carsharing vehicle in operation was equivalent to 8.3 private vehicles out of circulation *(6)*. This figure was obtained by combining data from an internal survey with figures found in the literature for both North America and Europe. It is important to stress that the methods used to achieve such figures are different from one case to the other, and highly depends on the way survey questions were posed to members. The main point is that carsharing is expected to add some benefit to the region where it is implemented in terms of reducing the number of vehicles. Accordingly, providing a better service that accommodates users' needs is important to help increase the market share of this form of transportation.

In 2001, Cervero *(7)* conducted a study at the launch of the City CarShare in San Francisco *(7)*. He surveyed the mobility behaviour of City CarShare members and non-members during three time intervals to determine how carsharing changed their mobility patterns during these periods. The members' vehicle-miles-traveled increased as users would switch from active modes of transportation, such as biking and walking, to using a shared vehicle. This was an indication that carsharing was already competing with sustainable transport modes. The author noted, however, that this may be due to the novelty of carsharing and the initial appeal of the service during a member's tenure. This hypothesis was later confirmed in a subsequent study; citing more judicious mobility choices, the authors determined that average VMT was lowered by 47% for members, but increased by 73% for non-members *(8)*. In a later study, Cervero, Golub & Nee *(9)* determined that the reductions in VMT occur a few months into membership but taper off a few years later. Overall, however, the addition of new members, cancels out the increase in VMT for seasoned users. Again, this highlights the benefits of having an efficient carsharing system that can attract new users. Attracting new users to a carsharing system requires a better understanding of the existing demand of carsharing systems.

Carsharing should be promoted along with other sustainable transport modes with the goal to reduce the number of vehicles on the road. A carsharing company only achieves success from increases in car usage and membership. However, both increases impose a burden on the system, since they will negatively affect the quality of the carsharing system by reducing the availability of vehicles for users to reserve. Accordingly, carsharing companies need to revisit their fleet size distribution on a regular basis to ensure a high level of availability of cars for users. This is very important for retaining current customers and attracting new ones, which leads to a higher level of usage and the highest possible revenue for a CSO. The focus of this research is to better understand the factors affecting car usage and availability in the Communauto system. Understanding these factors will help for proposing modifications to the existing network to ensure higher levels of availability and usage. Although some of the findings from this analysis will be agency specific due to the contextual nature of the study, the results will still be relevant to other agencies.

METHODS

This paper focuses on a case study of the Communauto CSO based in Montréal, Québec, which prides itself on being the oldest carsharing service in North America, and one of the fastest growing CSOs on the continent *(10)*. This section describes the research area, the carsharing operator's history, the services it provides, its fleet and summary indicators on membership. Montréal is Canada's second largest city and the largest metropolitan area in the province of Québec. As of the 2006 census, 3.7 million people resided in the Montréal census metropolitan area, and 1.8 million people lived in the city proper. Of those, 1.7 million travelled to work on a daily basis. 1.2 million (70.6%) used a car (either as a driver or a passenger), 367,000 (21.6%) relied on public transit, 98,000 (5.8%) walked to work, and 27,400 (1.6%) cycled. Montréal has an extensive public transit system comprised of four subway lines and 185 bus routes. The public transit system recorded 382 million trips in 2009.

Today, Communauto operates in four metropolitan regions throughout the province of Québec. These regions are Montréal, Québec City, Sherbrooke and Gatineau. The CSO operates a fleet of over 1,000 vehicles comprised of Toyota Echo, Yaris and Matrix models. The fleet is regularly renewed once vehicles have reached a certain mileage. Communauto focuses on short intracity trips. Most of its 310 stations are located within residential areas, although some are also placed at strategic transit nodes, or in central business areas to accommodate corporate members. Trips are priced by the hour, and for each kilometer travelled. The invoiced price includes gas, insurance and car maintenance. Members can reserve vehicles online or by telephone through an operator or an automated system. Figure 1 displays the dispersion of Communauto members and stations throughout the Montréal metropolitan territory. The Montréal metro region includes a total of 230 stations and 16,228 members.

In this research we develop two statistical models. The first is a monthly usage model, which concentrates on the number of hours a vehicle is reserved at a station. This model looks at the supply side of the vehicles to understand the factors that can lead to the highest level of usage, and ultimately, the highest possible revenue to the CSO. In developing this model we considered various units of analysis at the station level and over different time periods. Some vehicles do retire during the year and a high variance was present in the number of vehicles in each station. Our main criteria for selecting this unit of analysis is the consistency in the unit of measurement, in addition, it provides insight on the seasonality of usage. The second model primarily looks at demand and likelihood of reserving a vehicle during certain time periods. Availability is measured through a unique system that is present at Communauto. Automatic tests are performed by the Communauto reservation system twice a week. These tests attempt to reserve vehicles with 24-hour notice for every Wednesday and Saturday at every station in the network for the morning, afternoon and evening. The system records the result of each test, and assigns a binary value for either success or failure. We therefore have three results per station, twice per week for an entire year.

To understand both measures it was important to determine the station service area. A station service area is the area around a station that people are willing to walk to use a certain station. To determine this tolerable walking distance, each member's favourite station was determined through observing usage during a one year period. We then measured the network distance between that station and the member's home postal code. The 85th percentile of those values is used as the tolerable walking distance, 1.1 kilometres. Network buffers were then devised for each station using that value as a determinant of its catchment area. Although this method does simplify the catchment area, it is an acceptable method that is used in transit planning and operations when trying to understand the demand for transit around a bus stop.

INSERT FIGURE 1 AROUND HERE

Monthly usage model

The monthly usage model seeks to explain factors affecting vehicle usage at a station, using the number of monthly hours-reserved per vehicle as the dependent variable. Cancelled reservations were removed, but bookings which did not accrue mileage and remained active were preserved. It is assumed that a reservation, once booked and not cancelled, renders the vehicle unavailable to other users, whether the latter is used or not. This is characteristic of the Communauto reservation system, and maintains the integrity of the network for all users. Given that the dependent variable is based on a monthly value of each vehicle's usage, dummy variables were included to show the month during which the hours were accrued. This allows us to eliminate vehicles that were either taken out or added to the network during the course of the year. Each observation is compared to the month of December as the omitted variable. Measures of accessibility were also included to determine whether Communauto vehicle usage was related to the local accessibility to retail and employment. The usage model contains 8,673 observations, which is equal to the number of vehicles in operation during the year 2009 multiplied by the number of months the vehicles were in service. Table 1 describes the variables used in the model.

The usage model can be described as follows:

Monthly hours-reserved by vehicle = f (Vehicles, Vehicle age, Vehicles with child seats, Vehicles with air conditioning, Alternative vehicles, Métro stations, Member density, Income, Big box, Jobs gravity, Month in operation (January, February, March, April, May, June, July, ;August, September, October, November))

INSERT TABLE 1 AROUND HERE

The total number of vehicles, member density and income are expected to have a positive relationship with the dependent variable. The presence of accessories in the vehicle and the proximity to a métro station may also increase the number of hours-reserved. On the other hand, vehicle age and the number of alternative cars are expected to return a negative effect on the dependent variable. Hours-reserved are expected to be the highest during summer months. It is important to note that station location and size is determined based on several aspects in addition to existing customer density. One spatial consideration is the availability of space for a station and more cars. In addition, policy considerations include Communauto's desire to increase their market share in some areas and local municipalities' requests to increase carsharing coverage. Accordingly, a regular regression model won't be able to capture all these effects. In this model we will be using a multilevel regression method. More discussion regarding the selection of this modeling system will be presented in the analysis section. Table 2 includes summary statistics for the variables used in the vehicle usage model.

INSERT TABLE 2 AROUND HERE

Availability model

The second model aims to explain each test performed in the record of binary tests described in the previous section. In total, the model contains 70,775 observations from year 2009. In order to make the dataset manageable, the tests were separated into individual entries and coded to reflect which day the test was performed. Dummy variables were added for each test reservation period. Table 3 describes the variables used in the model. The availability model is a binary logistic regression model. It can be described as follows:

Outcome of the binary test = f (Test characteristics (3-hour AM, 3-hour PM, Winter, Spring, Summer, Wednesday), Station characteristics (Vehicles, Vehicle age, Vehicles with child seats, Vehicles with air conditioning, Alternative vehicles, Closest station, Distance to métro), Neighbourhood characteristics (Member density, Income, Big box, Employment))

INSERT TABLE 3 AROUND HERE

The odds of a test succeeding are expected to rise for shorter reservation periods, on Wednesdays and during the warmer seasons of the year (with a general exception for major holiday periods). Variables such as the number of members, jobs, the number of big box stores in the vicinity of the station and reservations placed on a Saturday should make it harder to book a car, and are expected to have a negative relationship with the odds of a reservation success. Table 4 presents summary statistics for the variables used in the availability model.

INSERT TABLE 4 AROUND HERE

ANALYSIS

Monthly usage model

The monthly usage model seeks to identify factors affecting overall usage of each Communauto vehicle, based on the total number of hours reserved monthly. While a standard regression was tested, the multilevel regression model was found to more accurately reflect station-level conditions, and it can bypass some of the limitations or bias that can be caused by the relationship between member density and station location. The multilevel modeling approach accounts for the hierarchal nature of data and accounts for within station variation and separates it from between stations variation. In other words, the effect of variables affecting two vehicles at the same station is different from the effect of the same variables affecting two vehicles at different stations.

Model evaluation

The purpose of these models is to evaluate the effect of the independent variables against monthly hours-reserved by vehicle. To achieve this goal, both a standard regression and a multilevel REML regression were performed. The latter model was selected to control for station-level characteristics and effects. Conceptually, we find two levels of analysis: the station at Level I, and the vehicle at Level II. The multilevel regression provides for both fixed and random effects. In this model, we have identified that member density as a random effect to account for the probability that some station characteristics are derived based on demand in the area. The likelihood ratio test did show a statistical significance at the 99% confidence level indicating that a multilevel regression model is more appropriate than a regular regression to estimate the number of hours-reserved by vehicle per month. Model 1 includes all the fixed effects and Model 2 provides estimates for both fixed and random effects using an unstructured variance-covariance structure (Table 5).

INSERT TABLE 5 AROUND HERE

The multilevel model shows that the total number of vehicles at the station has a major impact on the number of hours-reserved by vehicles. This indicates that stations with more vehicles are used more than stations with fewer vehicles. Furthermore, vehicle age negatively impacts the number of monthly hours-reserved by vehicle, indicating that members are less likely to use older vehicles. This relationship suggests that members may select stations based on the age of the vehicle fleet.

A variable accounting for the number of alternative vehicles at other stations within the station's buffer was included in the model to evaluate the effect of density of stations on the total daily number of hours-reserved. The negative relationship and coefficient demonstrate a dispersion effect within the network, whereby members located in areas where stations are numerous and close together will have the option of choosing an alternative station for their trips. This negative effect on the total number of hours-reserved demonstrates that the clustering of vehicles—and therefore stations—creates a competition effect within the network. However, the data is insufficient to establish that this may be a problem for the carsharing operator. The number of métro stations within the buffer has a positive relationship with the total monthly number of hours-reserved; however the relationship is not statistically significant. Each additional métro station within a Communauto station's tolerable walking distance buffer increases monthly hours-reserved by 2 hours and 28 minutes. Further research may indicate that high-order transit services in close proximity to a carsharing station increases the use of the latter. We can postulate that members who do not have access to vehicles close to their homes, or those who live outside the immediate coverage area provided by the CSO, use stations which are reachable by public transit. The fact that large Communauto stations are located close to métro stations is also of note, and should be encouraged. Adding stations in less densely populated areas may not be economically viable, but increasing the number of vehicles in the vicinity of métro stations might have the same intended effect, as well as providing service to those living close to that métro station.

Member density has a positive relationship with the number of hours-reserved monthly by vehicle. For each additional 100 members per square kilometre, the number of hours-reserved increases by 17 hours and 32 minutes. This relationship shows that it would be worthwhile to open stations in areas where members are concentrated. Income was also statistically significant. The relationship of income with monthly hours-reserved is negative but small. In fact, for each additional $1,000 in average income within a station's buffer, monthly number of hours-reserved per vehicle in operation decreased by 34 minutes and 11 seconds. This could be explained by the fact that persons with lower incomes are less financially able to take longer trips, which would accrue more hours per vehicle and per station. The relationship could also indicate that Communauto members have a lower average income than the general population, a finding that would contradict the operator's internal member survey data. It is impossible, however, to determine whether members would have misrepresented their income in the survey that Communauto conducted a few years ago.

Many carsharing users become members of the service to run errands, and benefit from the flexibility and capacity of a private car. In this aspect, we tested accessibility to various types of retail. Accessibility was measured using a cumulative opportunity measure of accessibility, which counts the number of certain type of stores within a 30 minutes travel time threshold by car. Only big box stores showed an impact on the model and, accordingly, they are the ones reported in here. Big box stores are a common destination for carsharing members who may not be able to travel to commercial centres by public or active modes of transportation. Furthermore, carrying heavy loads on transit, by foot or by bicycle is difficult, and makes a shared vehicle quite useful. The model indicates that the number of big box stores within 30 minutes driving time from a Communauto station has a positive relationship with the number of hours-reserved by vehicle. For each additional store within 30-minute of travel time by car the number of monthly hours-reserved increases by 27 minutes and 23 seconds. The model should not be interpreted to signify that Communauto should locate stations in areas where big box stores are numerous and close together. In fact, this advantage would be cancelled out by a low member density.

The employment accessibility variable indicates that each 1,000 additional jobs within a 30-minute driving time of a station decreases monthly usage by 31 minutes and 44 seconds. A high number of jobs in close proximity to a Communauto station reduces the overall usage of vehicles for that station. This relationship may reflect the fact that the service is primarily geared towards individual members. This can be partially explained by the fact that corporate members have a broader access to rental car company services and may forfeit the use of Communauto vehicles for longer trips, whereas individual members may benefit from using carsharing vehicles even on longer trips. This can also be explained by our findings while determining the service area, where 85% of the members used a station within 1.1 km from their home.

While the month in operation variables are elements out of the control of Communauto, they do confirm trends established in the methodology section. January through June and September through November have lower usage rates compared to December (the omitted variable), with the penultimate month of the year having the lowest usage overall. The summer months of July and August have higher usage than December by 50 and 58 hours respectively. It is important to note that these figures also take into account old and damaged vehicles being taken out of service, and new vehicles introduced into the fleet throughout the year. The model confirms that the summer months, as well as the end-of-year holiday period, are the busiest for Communauto. Usage dwindles in November, and throughout the cold Montréal winter, only to increase again in the spring. The implications of the season on any carsharing service should be carefully considered by the CSO, and clearly affects the quality of the service throughout the year. Communauto should seek innovative ways to increase their fleet size during these months with minor costs. The increase in usage is expected to have a direct effect on availability, which is one of the main variables affecting customer satisfaction.

Availability model

The availability model seeks to determine which factors influence the probability of obtaining a successful reservation using binary tests performed by the Communauto reservation system throughout the year 2009. Table 6 provides the model associated with this regression. The model establishes that a 3-hour reservation in the morning is 21% less likely to be successful compared to a 3-hour reservation in the evening; likewise, a 3-hour reservation during the afternoon period is 62% less likely to be fulfilled than a 3-hour reservation in the evening. A test performed for a Wednesday reservation is 882% more likely to be successful than a reservation for a Saturday. Reservations are also less successful in the winter, spring and summer compared to the fall by 7%, 17% and 32%, respectively.

INSERT TABLE 6 AROUND HERE

In terms of station characteristics, the model establishes that each additional vehicle at the station increases the likelihood of a booked reservation by 30%. The presence of a vehicle with a child seat increases the chance of successfully booking a reservation by 8%; the variable for vehicles with air conditioning does not return a statistically significant relationship. The age of the vehicles also has a positive relationship with their availability: each additional vehicle year of age increases the probability of a reservation fulfilled by 10%. Finally, each additional alternative vehicle within the station's buffer increases the probability of a reservation succeeding by 2%.

In terms of proximity to another station, the closest station variable does not have a major impact on the binary test outcomes. However, the *z*-statistic provides the direction of the relationship. The closest station has a positive relationship to the outcome of the test. On the other hand, the relationship between the outcome of the binary test and the number of métro stations in the immediate vicinity of the stations is negative: each additional métro station decreases the probability of the reservation being fulfilled by 2%. A higher member density decreases the probability of a reservation succeeding by 1%. This follows our expectations that a larger concentration of members will increase the use of vehicles, and in turn, lower their availability. The relationship to income is marginal but negative. The presence of big box retail stores within a 30-minute driving time of the station also produces a negative relationship; each additional retail store in this radius decreases the probability of a successful reservation by 1%. Finally, jobs located within a 30-minute drive return a positive, but marginal, relationship.

Overall, the relationships in the availability model correspond with the ones found in the multilevel usage model described in the previous section. It is logical that the effect of these variables will be concurrent from one model to the other. For example, member density increases usage and decreases availability. Some variables direct both models in the same direction; the number of vehicles at the station increases both usage and availability. This is an important finding and indicates that there may be a vehicle threshold above which both availability and usage remain high, which is a favourable situation for the members and the CSO management alike.

CONCLUSION

Throughout this paper we have considered that low availability was a negative factor and high availability was a positive factor. While this may be counterintuitive if the CSOs sole purpose is to increase revenues at all costs, a low availability leads to member frustration and to overall dissatisfaction with the service. After all, carsharing users become members in order to gain access to a fleet of vehicles and not to be denied service whenever they want to use a car. With this in mind, it is important to remember that the ideal situation is the combination of high availability and high vehicle usage, which ensures that users are satisfied with the service and that vehicles are used, thereby ensuring revenues for the carsharing operator.

The size of a carsharing station was shown to have a large impact on both variables. Larger stations offer more vehicle options and have, by definition, a larger catchment basin than smaller stations. Installing large stations is a big challenge in urban areas due to space limitations. Carsharing companies would need to rent or purchase space in nearby parking lots. Another option is to allocate more on-street parking space to carsharing companies. In addition, the seasonal impact on both availability and usage was clear. During the summer months fewer vehicles are available, which requires an increase in the fleet size in term of number of stations, as well as number of cars in each station. This can be achieved through adding personal vehicles owned by existing members to the carsharing fleet during these periods. Communauto has recently started a similar program to increase its fleet size during the summer, while minimizing additional capital costs. Moreover the seasonality effect can be used as a guide to decide when certain vehicles should go into maintenance, which will maximize efficiency.

The effect of various retail types was tested in this study. Big box retail was the only business type that showed statistical significance in both models with a magnitude worth reporting in a model. This reflects that big box trips could be of interest to carsharing customers. Further investigation through customer surveys is required to validate this finding. Stations located near Métro stations decreased the availability of a vehicle at a station, but increased station usage. Although the magnitude of this variable is not high, it shows potential for current efforts to encourage multimodalism. Increasing the number of vehicles and stations near transit stations and promoting public transit use is expected to increase.

Vehicle age was considered as one of the key factors when it came to increasing availability and decreasing usage. It also shows that members tend to prefer newer vehicles. This finding can help determine when vehicles need to be replaced. Vehicle with car-seat is another factor that leads to increasing availability and decreasing usage. This can be explained by the demographic characteristics of carsharing users in the study region. Nonetheless it is one of the variables that requires future study through a customer-based survey to understand why it has a negative effect on usage. Finally, the findings from this study can be used in directing future actions by the CSO. These actions can be split into 5 categories: support growth at stations, add vehicles, promote stations, renew fleet and cut services. Stations can be grouped into these categories using existing information obtained from stations and vehicle usage.

The next step is to increase membership in areas that are not inherently attracted to such a novel service. Persons who are accustomed to owning a car will not make the choice to give it up easily; Communauto's service must be up to par in terms of availability, quality and flexibility. One major bottleneck in expansion, however, is the lack of affordable parking spaces that are also accessible, safe and well-located. Concurrently, scarce parking may be a strong incentive for car owners to become members of the service when they realise that parking costs are included in the package provided by the carsharing operator.

Given the novelty of carsharing, research on the operation of a successful network is scarce. While local and regional characteristics make standardisation more complex, the research presented reveals preferences of users that can be used by other carsharing operators to guide their system's growth. Additional capacity may be needed in high employment areas to both fulfill the needs of corporate members, and ensure individual members have the opportunity to begin trips from their workplace using the service. Another study should investigate demand for carsharing service in areas that are not currently served by a carsharing operator. This can be done using the existing models and generating various scenarios. While the operator has made a foray into the suburbs, it is not clear that carsharing is adapted to the suburban built form and to the specific mobility needs of persons in low-density areas. A proper demand model would establish where service is needed based on the performance of the existing network, which may initiate a domino effect which would eventually reach outlying suburban areas.

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Table 1: Monthly usage model: variables

Variable name	Description
Vehicles	Number of vehicles at the station
Vehicle age	Average age of vehicles at the station, in model years
Vehicles with child seats	Number of vehicles with child seats at the station
Vehicles with air conditioning	Number of vehicles with air conditioning at the station
Alternative vehicles	Number of vehicles in other stations within the station's buffer
Métro stations	Number of métro stations within the station's buffer
Member density	Number of Communauto members within the station's buffer per square kilometre
Income	Average income of residents within the station's buffer, in dollars
Big box	Number of big box stores located within 30 minutes by car
Employment	Number of jobs located within 30 minutes by car
Month in operation	
January	Dummy variable for vehicles in operation during the month of January
February	Dummy variable for vehicles in operation during the month of February
March	Dummy variable for vehicles in operation during the month of March
April	Dummy variable for vehicles in operation during the month of April
May	Dummy variable for vehicles in operation during the month of May
June	Dummy variable for vehicles in operation during the month of June
July	Dummy variable for vehicles in operation during the month of July
August	Dummy variable for vehicles in operation during the month of August
September	Dummy variable for vehicles in operation during the month of September
October	Dummy variable for vehicles in operation during the month of October
November	Dummy variable for vehicles in operation during the month of November
Dependent variable	Monthly hours-reserved by vehicle

Table 2: Summary statistics for monthly usage model

	Minimum	Maximum	Mean	Standard deviation
Vehicles	0.08	20.33	5.67	4.437
Vehicle age	1.00	10.00	4.35	1.908
Vehicles with child seats	0.00	1.00	0.112	0.316
Vehicles with air conditioning	0.00	1.00	0.362	0.481
Alternative vehicles	0.00	80.00	22.31	19.51
Métro stations	0.00	6.00	1.595	1.329
Member density	1.90	652.15	266.38	192.05
Income	23,589.40	91,695.80	37,777.02	8,307.75
Big box	30.00	163.00	125.01	19.88
Employment	180,292.20	1,327,758	1,050,591	218,446.40
Month in operation				
January	0.00	1.00	0.0747	0.263
February	0.00	1.00	0.0741	0.262
March	0.00	1.00	0.0759	0.265
April	0.00	1.00	0.0804	0.272
May	0.00	1.00	0.0823	0.275
June	0.00	1.00	0.0865	0.281
July	0.00	1.00	0.0880	0.283
August	0.00	1.00	0.0867	0.281
September	0.00	1.00	0.0877	0.283
October	0.00	1.00	0.0874	0.282
November	0.00	1.00	0.0873	0.282
Dependent variable: Monthly hours-reserved by vehicle	2.00	1,196.50	328.15	105.27

n = 8,673

1 Table 3: Availability model: variables

Variable name	Description
Test characteristics	
3-hour AM	Dummy variable for 3-hour reservations in the morning
3-hour PM	Dummy variable for 3-hour reservations in the afternoon
Wednesday	Dummy variable for tests performed on a Wednesday
Winter	Dummy variable for reservations from December through February
Spring	Dummy variable for reservations from March through May
Summer	Dummy variable for reservations from June through August
Station characteristics	
Vehicles	Number of vehicles at the station
Vehicles with child seats	Number of vehicles with child seats at the station
Vehicles with air conditioning	Number of vehicles with air conditioning at the station
Vehicle age	Average age of vehicles at the station
Alternative vehicles	Number of vehicles in other stations within the station's buffer
Closest station	Distance to the closest station, in metres
Métro stations	Number of métro stations within the station's buffer
Neighbourhood characteristics	
Member density	Number of Communauto members within the station's buffer per square kilometre
Income	Average income of residents within the station's buffer, in dollars
Big box	Number of big box stores located within 30 minutes by car
Employment	Number of jobs located within 30 minutes by car
Dependent variable	Outcome of the binary test 1= vehicle available

Table 4: Summary statistics for availability model

Variable name	Minimum	Maximum	Mean	Standard deviation
Test characteristics				
3-hour AM	0.00	1.00	0.333	0.471
3-hour PM	0.00	1.00	0.333	0.471
Wednesday	0.00	1.00	0.496	0.499
Winter	0.00	1.00	0.392	0.488
Spring	0.00	1.00	0.169	0.375
Summer	0.00	1.00	0.252	0.434
Station characteristics				
Vehicles	0.00	20.00	3.36	2.89
Vehicles with child seats	0.00	4.00	0.388	0.635
Vehicles with air conditioning	0.00	11.00	1.55	1.66
Vehicle age	0.50	8.00	3.04	1.34
Alternative vehicles	0.00	80.00	19.11	19.32
Closest station	27.02	13,052.54	609.83	643.74
Métro stations	0.00	6.00	1.53	1.45
Neighbourhood characteristics				
Member density	1.90	652.15	205.30	179.19
Income	23,589.41	91,695.75	38,559.48	9,755.69
Big box	30.00	163.00	121.13	25.58
Employment	180,292.20	1,327,758	1,006,801	275,533.50
Dependent variable: Outcome of the binary test	0.00	1.00	0.487	0.499

n = 70,871

Table 5: Monthly usage multilevel models

	Model 1		Model 2 (Unstructured)	
Fixed effects	Coefficient	*z*-statistic	Coefficient	*z*-statistic
Intercept	345.98	20.13***	352.07	19.24***
Vehicles	2.42	2.65***	1.90	2.22**
Vehicle age	-8.69	-10.55***	-8.77	-10.66***
Vehicles with child seats	-18.31	-5.48***	-18.41	-5.51***
Vehicles with air conditioning	-4.11	-1.22	-5.04	-1.50
Alternative vehicles	-0.839	-2.87***	-0.752	-2.80***
Métro stations	3.22	1.75*	2.49	1.33
Member density	0.188	5.47***	0.175	5.54***
Income	-0.000423	-1.68*	-0.000570	-2.17***
Big box	0.596	2.92***	0.456	2.71***
Employment	-0.000541	-2.74***	-0.000529	-2.55***
Month in operation				
January	-74.95	-15.35***	-74.57	-15.34***
February	-73.68	-15.04***	-73.29	-15.02***
March	-52.12	-10.78***	-51.73	-10.74***
April	-63.56	-13.58***	-63.30	-13.54***
May	-28.62	-6.19***	-28.46	-6.17***
June	-22.76	-5.02***	-22.74	-5.02***
July	50.58	11.23***	50.57	11.23***
August	58.21	13.01***	58.83	13.01***
September	-41.93	-9.30***	-41.92	-9.30***
October	-30.36	-6.73***	-30.35	-6.73***
November	-80.46	-17.83***	-80.44	-17.83***
Random effects	Standard deviation	Standard error	Standard deviation	Standard error
Intercept	26.66	1.95	39.22	4.07
Member density			0.0913	0.0216
Residual	88.18	0.679	88.17	0.679
Model fit statistics	Estimate		Estimate	
Deviance	102,610.30		102,602.36	
AIC	102,654.40		102,654.30	
BIC	102,838.10		102,823.90	
Dependent variable: Monthly hours-reserved by vehicle		n = 8,673		
*** = 99% confidence level ** = 95% confidence level * = 90% confidence level				

Table 6: Availability model

Variable name	Odds-ratio	*z*-statistic
Test characteristics		
3-hour AM	0.7925	-10.71***
3-hour PM	0.3827	-43.19***
Wednesday	8.82	116.54***
Winter	0.9323	-2.80***
Spring	0.8267	-6.37***
Summer	0.6833	-13.95***
Station characteristics		
Vehicles	1.3046	37.99***
Vehicles with child seats	1.0829	4.79***
Vehicles with air conditioning	0.9919	-0.83
Vehicle age	1.1036	11.43***
Alternative vehicles	1.0163	13.67***
Closest station	1.0002	12.21***
Métro stations	0.9795	-2.85***
Neighbourhood characteristics		
Member density	0.9971	-21.39***
Income	0.9999	-3.89***
Big box	0.9976	-3.08***
Employment	1.0001	6.90***

Dependent variable: Outcome of the binary test
n = 70,871 Log likelihood = -37,858.56 Model χ^2 = 22,484.96
McFadden pseudo-R^2 = 0.2290
Minimum significance: *** = 98% confidence level

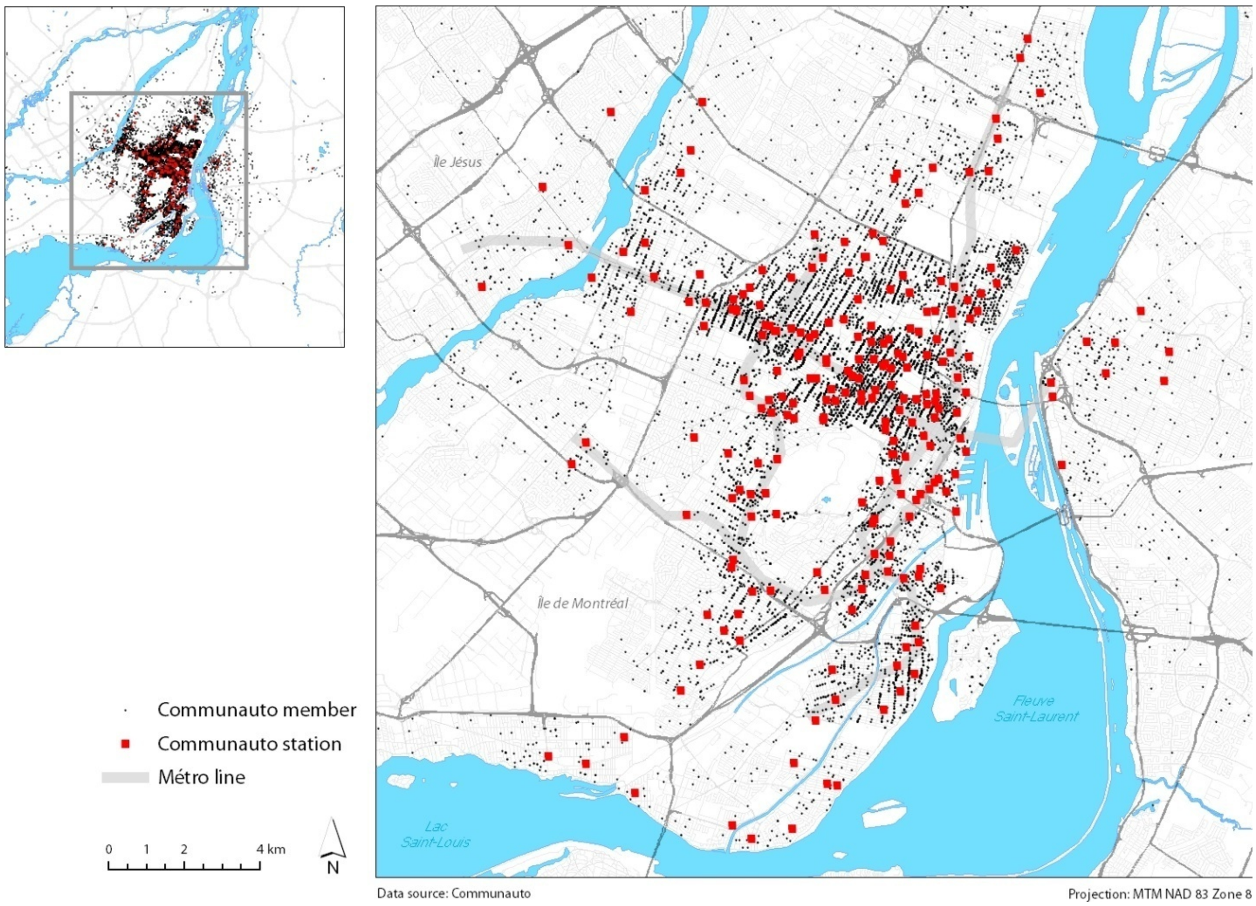

Figure 1: Communauto members and stations in the Montréal metropolitan territory.