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Identification of the minimum size of the shared-car fleet required to satisfy car-driving trips in Montreal

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Abstract This paper examines how many cars would be required to fulfill all car driver trips in a metropolitan area if these cars were shared rather than privately controlled. It proposes a twofold analysis regarding the use of cars in urban areas using data from a large scale Origin–Destination travel survey conducted in the Greater Montreal Area in 2008 as case study. In a first step, the use of privately owned cars and their level of usage are assessed through indicators such as the proportion of daily time parked at home location, parked elsewhere and travelling. In the region, 27 % of the owned cars are not used during a typical weekday. According to the estimations, a car will, on average, be parked more than 95 % of the time. In a second step, the research simulates a full-scale mutualization of cars in the region. Cars required to fulfill all car driver trips observed in the survey are generated based on two hypotheses of access distance to the shared cars (250 and 500 m cells). It was found that between 48 and 59 % of the current fleet of privately owned cars would be sufficient to fulfill all car driver trips at the metropolitan level.

Keywords Carsharing · Modal choice · Car driver trips · Parking

Introduction

Reducing automobile dependence is a key component of a wide set of transportation and sustainability plans and strategies. For instance, in the Montreal transportation plan, the city proposes to reduce automobile dependence, to question the hegemony of cars in cities,

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and to promote alternate modes of transportation such as different ways of using cars namely by sharing them (Ville de Montréal 2008).

There is currently an increasing number of carsharing, bikesharing and other sharing services being implemented around the world. More and more people are changing their behaviors and combining a variety of transportation modes to fulfill their needs. In Montreal, more than 1000 shared cars are supplied in stations by Communauto and this number keeps growing up. Since 2009, a bikesharing system (BIXI) supplying some 5000 bikes (in 2013) is operating from early April to late November. Since the summer of 2013, some shared, non-station based electric cars are also made available by Communauto. Moreover, a new system called Netlift is gaining attention: it offers a new tool to facilitate combination of rides among travelers. Finally, taxi sharing is also emerging in the city. This phenomenon is not specific to Montreal. Transportation is in transition in many cities around the world, transforming travel patterns and transport supply. Those transportation alternatives are still viewed as marginal modes at the metropolitan scale, but they already fulfill the travel needs of a non-negligible proportion of households in some neighborhoods. For instance, in some central neighborhoods of Montreal, up to 11 % of households are members of a regular carsharing service.

In this context, it seems more than relevant to question the current use of automobiles in urban areas and to assess the impacts of a more judicious use. After all, data from many countries indicate that cars are parked at least 95 % of the time (Bates and Leibling 2012; Shoup 2011). With this in mind, this paper proposes a twofold analysis aiming at better understanding and measuring the mobility of cars with the help of various usage indicators, and estimating the impacts of mutualization of all cars available in an area. The latter may appear as an unrealistic scenario, but it aims at illustrating how important is the gap between what is theoretically possible with respect to sharing of cars and the reality. Hopefully, it will help questioning the status quo regarding car ownership and usage.

The paper is organized as follows. First, some background elements relevant to the research are proposed. Unfortunately, no equivalent research has been found in the literature. Hence, discussions in relation with the sharing economy as well as figures related to carsharing have been examined. Then, the general methodology is exposed, namely the datasets used for the analysis as well as the procedures developed for the computations. The next section relates to the analysis of car usage in the Montreal region in 2008. Key figures with respect to car ownership and level of usage are provided. Results focusing on the deterministic computation of two full-scale sharing scenarios are then presented and discussed. A discussion concludes the paper.

Background

The sharing economy

With its characteristics of simplicity and interactivity, Internet has broadened the sharing possibilities between people, whether it is sharing of information (Wikipedia, since 2001), of photos (Flickr, since 2004), of videos (Youtube, since 2005), of opinions (Twitter, since 2006), or of personal experiences (Facebook, since 2006). Also called “collaborative consumption”, and closely linked to the soaring of online social networking, the sharing economy puts emphasis on access (to goods or services) rather than on ownership (Botsman and Rogers 2010). In some ways, it represents a new kind of trading scheme, based on new forms of relations between individuals, made possible by the emergence of digital information systems.

The sharing economy has already contributed to redefine transportation modes (The Economist 2013; The Week 2012). In many countries around the world, bikesharing systems (Bixi, Velib, Ecobici, Niceride, Call-a-bike, Mobilicidade, etc.) and carsharing systems (Communauto, Autoshare, Autolibre, Zipcar, GoGet, Stattauto, Mobolib, etc.) have been implemented, which allows people to travel without owning a vehicle.

From these public or private systems offering services to a user, things have now evolved—thanks to Internet possibilities—to peer-to-peer rental services, in which you can either pay to borrow someone else's car (Buzzcar, Getaround, RelayRides, Tamyca, Wheelz, Whipcar, etc.), get free airport parking by renting out your car to other air travelers while you are gone (FlightCar), or offer taxi-like services (Lyft, SideCar, Uber, Weeels, etc.), or even rent your personal parking spaces (Airbnb for cars) (The Economist 2013).

With the expansion of this type of services, one might expect that more and more people will favor access to a transport mode over vehicle ownership, all the more so as many have to live now on a tight budget. In such a case, we could witness a decrease in the number of cars in use, and consequently, a reduction of congestion, but also, an increase in access. In their efforts to improve the offer of transport services, stakeholders should take into account this new reality.

An increasing market for shared modes

Carsharing markets show a growing trend in the number of users as well as in the number of operators: in North America for instance, the membership of carsharing operators reached one million users in January 2013, an increase of 24.1 % in the U.S. and of 53.4 % in Canada over just a year (Shaheen and Cohen 2013). According to studies of carsharing markets, the worldwide carsharing membership is expected to grow from 2.3 million in 2013 to more than 12 million by 2020 (Berman et al. 2013), and could possibly reach 26 million (Leveque 2011).

In 2005, (Shaheen et al. 2005) estimated the growth potential of carsharing in major metropolitan regions of North America at 10 % of individuals over the age of 21. However, the arrival of new players, such as automakers (Daimler's car2go carsharing program) and car rental companies (Avis acquired Zipcar in 2013), combined with the emergence of new business models (one-way carsharing, peer-to-peer carsharing) and of new programs targeting other market segments (businesses, residential developments, government fleets, low-income markets, college and university markets) will probably lead to further growth and diversification of the market (Shaheen and Cohen 2013, Shaheen et al. 2009).

These data illustrate the emergence of new forms of mobility, relying less on car ownership and more on sharing services, especially in big cities, where congestion and parking restrictions prevail. In this regard, Shaheen et al. (2009) note that one of the main impacts of carsharing on transportation is a reduction in vehicle ownership as well as a reduction in VMT (Martin et al. 2010). Using data from a North American carsharing member survey, Martin et al. (2010) estimated that carsharing has removed between 9 and 13 vehicles from the road for each carsharing vehicle. The generalization of smart mobile devices will, without any doubt, favour the growth in carsharing, by simplifying its logistics.

General methodology

This section provides details regarding the dataset used as well as the process developed to analyze current use of cars as well as compute a full-scale mutualization of cars.

Travel survey data

This research relies on data collected during the 2008 large-scale Origin–Destination (OD) survey conducted in the Greater Montreal Area. In the region, such surveys have been conducted since 1970 at approximately every 5 years. They are typically conducted by phone and gather data on one particular day of travel during the fall period. The total sample amounts to some 4–5 % of the residing population. Trip data are collected from all people aged 5 years and older and belonging to surveyed households. In addition to data on trips (time of departure, mode sequence, trip purpose, trip ends, etc.), details regarding the household (home location, car ownership) and people (age, gender, main occupation) are gathered.

Car ownership of households along with car driver trips are the two main variables required for this research. Figure 1 describes the information available and points to the fact that using the available information, it is not possible to know which car is used, within a household owning more than one, for each car driver trip. Hence, we are proposing the concept of "equivalent-car" that will allow to count the number of cars used by the household without differentiating between car 1 and car 2 for instance. Consequently, if all car driver trips of a household could have been done using a single car, we will suppose it is the case even if the household owns more than one car and that, in reality, it is possible that different cars have been used in sequence.

As shown below, the sample gathers some 66,124 households. On one side, almost one-third of households have declared no car driver trip during the day of interview. Among these households more than 43 % do own at least one car. On the other side, less than 0.5 % of households declaring car driver trips do not own a car. These trips could relate to the use of shared cars (system, peer to peer or informal) but the survey questionnaire does not allow the validation of such hypothesis.

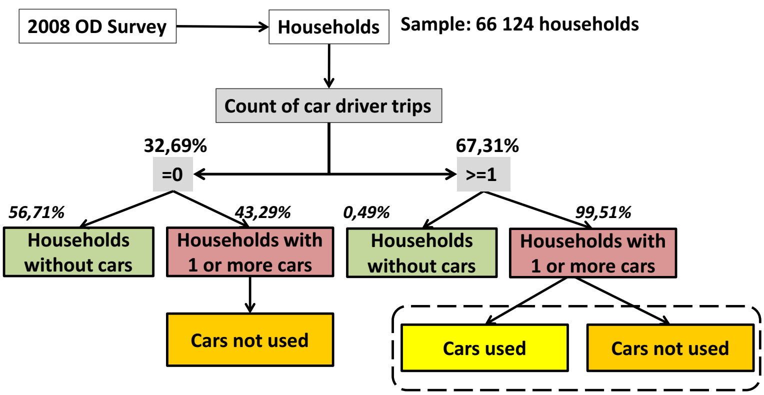

Fig. 1 2008 OD survey sample and segmentation according to car use

Process for the analysis of current use of cars

The first step of the methodology relates to the assessment of the current use of cars owned by the households living in the region. As part of the questionnaire, households were asked to provide the number of cars they own. Using expansion factors of the households (estimated to allow statistical inference to the entire household population of the region), it is possible to estimate the total number of privately owned cars. In order to understand the current use of cars, a validation process was implemented. The purpose is to estimate the number of cars required to fulfill all car driver trips. The output of the process can then be used to compare with the declared ownership. Figure 2 illustrates this process: car driver trips of each household are first examined to generate trip end events with timestamps (departure time for departure events and arrival time for arrival events). Then, home-based events are sorted based on timestamps: for each departure event, if a car is available at the home location then it is used for the trip otherwise a car is generated for the purpose; for each arrival event, the number of car available at the home location is incremented by one. The end result of the process is the number of cars generated to fulfill all car driver trips of each household.

Computation algorithm of full-scale mutualization of cars

The computation algorithm used to estimate the number of shared cars that would be required to fulfill all the observed travel needs of car drivers is similar to the one used to validate current usage of cars within households. The objective is to

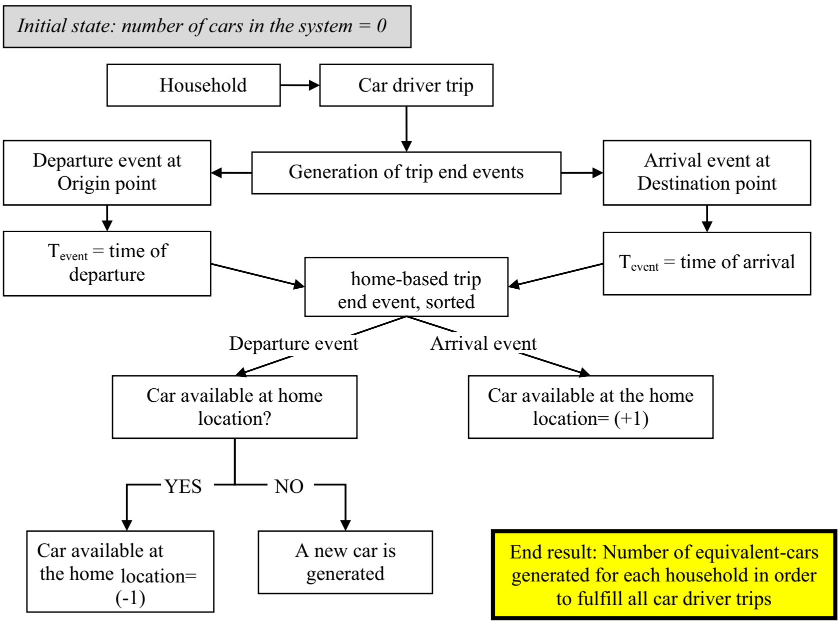

Fig. 2 Process to estimate the number of equivalent-cars that each household needs to meet its typical daily travel needs (car driver trips only)

determine the upper limit, with very few constraints, of shared cars needed to fulfill the current travel needs of drivers. The differences with the previous estimation lie on the spatial unit which is used for the computation and in the consideration of all trip events, not just the home-based ones. Obviously, this algorithm is based on several assumptions. First, we assume that travel demand is constant and will not change due to the fact that cars are shared instead of privately owned. Also, we assume that the entire population has no objections to share their car and that the car used for their trips meets their travel needs. Moreover, we assume that there is no searching time for a vehicle.

For the computation scenarios, two sizes of cells are used that relate to two hypotheses regarding the distance drivers accept to walk to get a car for their trips. We suppose that this drivers accept to walk such distance notwithstanding their location in the region. As shown in Fig. 3, two trip end events are created from each car driver trips available in the travel survey data file: one event, at the origin point, inherits the time of departure while the destination point inherits time of arrival. Trip ends are then linked to zones and processed sequentially. If, for a specific origin trip end, there is no car available in the zone, a new one is generated while each destination trip end adds to the number of cars available in the zone. The computation is conducted with two sizes of cells: 500 and 250 m. This translates into hypothesis that driver will accept to walk at most 707 m (diagonal distance of a 500 × 500 m cell) in the first case and 354 m in the latter one (diagonal distance of a 250 × 250 m cell). Both distances are within threshold walking distance for adults as proposed by Morency et al. (2014).

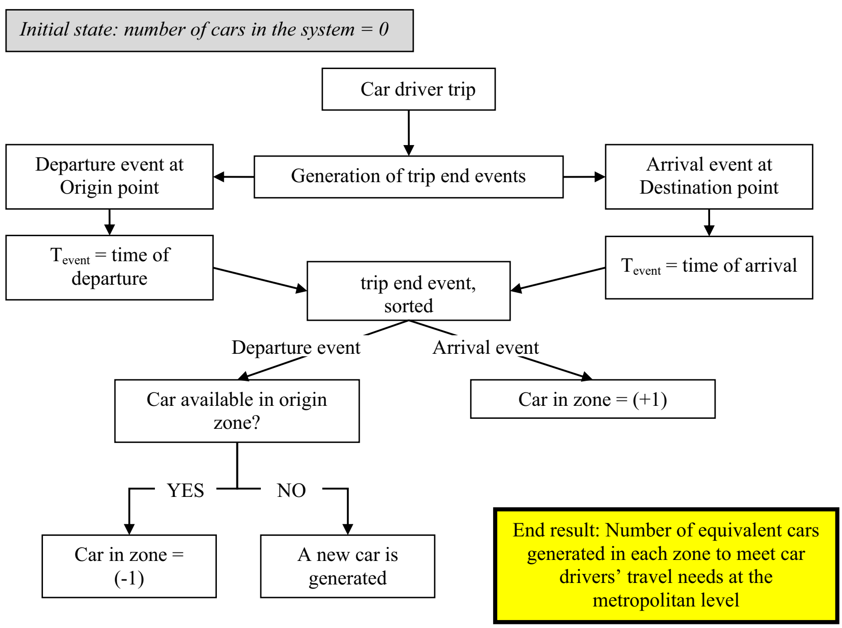

Fig. 3 Process to estimate the number of equivalent-cars to be generated in each zone to fulfill car drivers' travel needs

Travel times estimation

In the OD survey questionnaire, people are asked to provide time of departure for each trip, but no information is collected regarding either trip duration or time of arrival. In this context, it is required to determine duration for each car driver trip. For this purpose, an ad-hoc procedure was developed to estimate travel times using a set of GPS points providing extensive knowledge on spot speed on the transportation network, hence allowing to correct free-flow time to take into account delays from congestion. Using a road network codified in Open Street Map as well as the open-source calculator SpatiaLite, shortest paths were computed on the network. Travel time corrections are then applied based on observed speeds for four time periods (AM/PM peak, day and night). Additionally, time penalties of 10 s are added for each change in road or intersection. This process allows correcting travel times for 98 % of the trips.

Current use of cars

According to the 2008 OD survey, the fleet of privately owned cars in the Greater Montreal Area (GMA) reached 2.1 million cars for that year. This number was then compared to the result of the validation process previously exposed that estimates the number of equivalent cars required to fulfill car driver mobility needs. Key results are discussed below.

Overall, some 570,000 equivalent-cars are not used during a typical weekday of fall (27 % of the estimated total fleet). This proportion varies throughout space: it is higher in urban areas and more or less decreases with distance from the Central business district (CBD). Hence, 25 % of the households own more cars than what is required to fulfill their daily typical travel needs (for car driver trips). Figure 4 presents the number and proportion of equivalent-cars not used by the households, based on home location. The proportion varies between more than 46 % (for CBD residents) and 24 % (for outer suburbs residents).

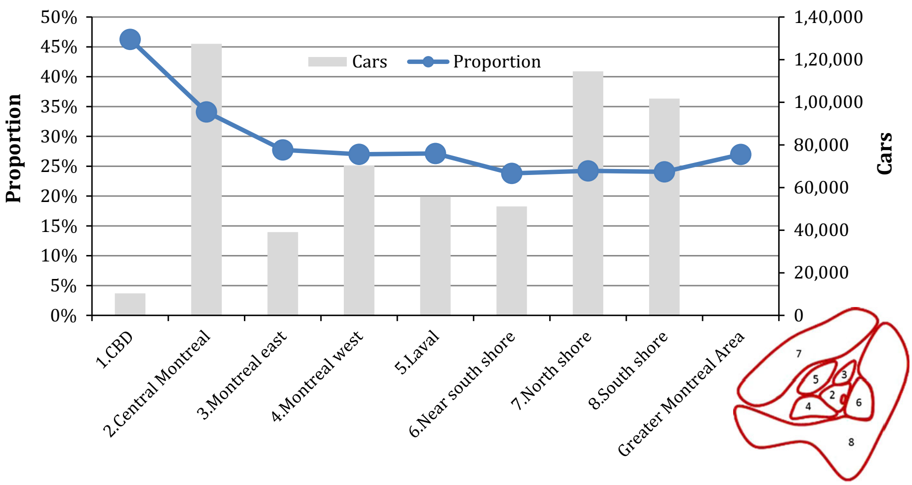

Fig. 4 Number and proportion of the equivalent-cars not used by the households during a typical day of fall, by region of home location (OD 2008)

Table 1 Statistics on the use of currently owned cars according to region of home location

	Time at			% of the time parked	Mean distance per day (km)	Mean speed (km/h)
	Home location (h)	Parked elsewhere (h)	Travelling (min)			
Central business district (CBD)	17.2	5.7	67.5	95.4	21.0	18.7
Montreal-center	16.6	6.3	69.0	95.4	18.9	16.4
Montréal-east	16.2	6.6	69.5	95.0	21.2	18.3
Montréal-west	16.2	6.7	68.5	95.4	23.6	20.7
Laval	16.3	6.6	67.0	95.4	22.2	19.9
Near south shore	15.9	6.9	70.5	95.0	24.5	20.9
North shore	16.0	6.8	74.8	95.0	35.7	28.6
South shore	16.0	6.7	74.2	94.6	34.9	28.2
Greater Montreal	16.2	6.7	71.3	95.4	27.7	23.3

The results of the validation process also allow the estimation of various indicators describing the use of cars (Table 1). On average, a car will spend 67 % of its time parked at home, 28 % of its time parked elsewhere, and a slightly more than 5 % travelling (that could be considered the productive time). These statistics vary little among regions, with lower proportion of travelling time in urban regions. Kilometers travelled are higher for suburbs as well as mean speed, which is coherent with wider availability of highways and lower congestion rates further away from CBD. With such a low proportion of productive times, it is worth examining how this mode can be used in a more efficient way.

What if cars were mutualized?

To assess the possible efficiency gains with respect to the use of cars, computations were conducted using the previously described method. The underlying hypothesis is that cars are public transportation tools than can be accessed by any driver. Two scenarios are estimated, differing only with respect to the maximal access distance to a car. A car is considered available for a driver if it is located in the same cell as the origin point of its trip.

Figure 5 presents the results of the computation in terms of cars required and patterns of generation during a typical weekday of fall, for the two scenarios. At 9 am, 70 % of the required cars have already been generated for the 500 m scenario and 67 % for the 250 m scenario, confirming the high concentration, in space and time, of car driver travel demand during the AM peak period. Computations estimate that 1.3 million cars would be sufficient to fulfill current travel needs (expressed as daily car driver trips) if they were mutualized (cells of 250 m), or even less if people accept to walk a little bit more (1.0 million cars for cells of 500 m). As shown in Fig. 6, these numbers compare favorably to observed ownership (2.1 million cars) and current level of usage (1.5 millions). Actually, if cars were mutualized, we could reduce the number of owned cars by 40.7 or 52.0 % for the 250 and 500 m scenarios respectively, and by 18.8 or 34.1 % the proportion of cars used during a typical day for the same scenarios.

Moreover, indicators previously estimated for currently owned cars in Table 1 are calculated for both scenarios and are shown in Table 2. Of course, sharing cars would

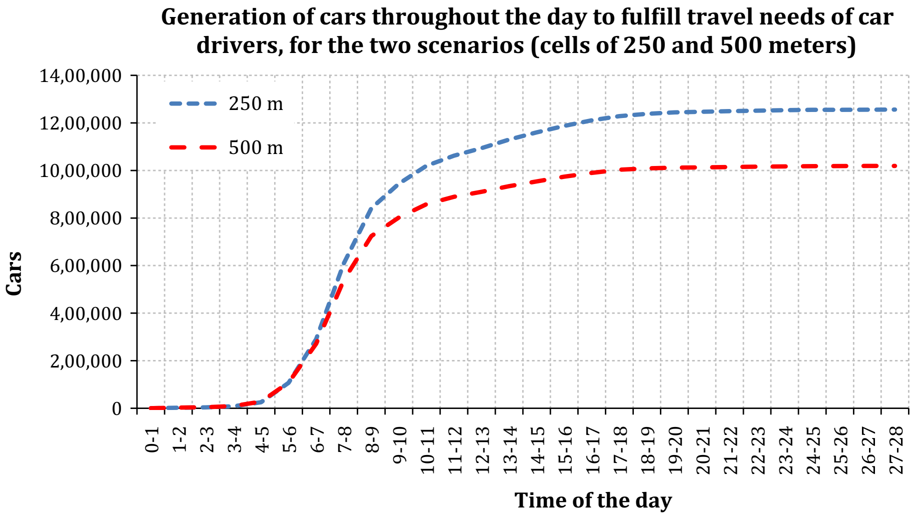

Fig. 5 Generation of cars throughout the day to fulfill travel needs of car drivers, for the two scenarios (cells of 250 and 500 m)

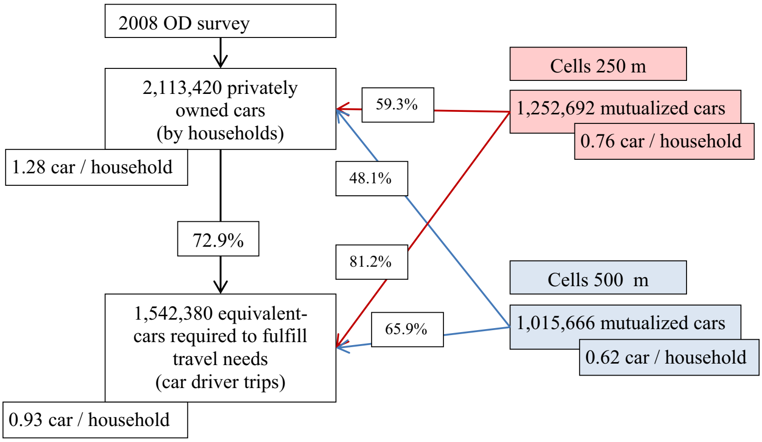

Fig. 6 Results of the computations and comparison with car ownership and required equivalent-cars

Table 2 Statistics on the use of currently owned cars and mutualized cars from the two scenarios for the Greater Montreal Area

	Time at			% of the time parked	Mean distance per day (km)
	Home location (h)	Parked elsewhere (h)	Travelling (min)		
Currently owned cars	16.2	6.7	71.3	95.4	27.7
250 m scenario	13.2	8.3	87.8	93.9	34.1
500 m scenario	10.7	10.2	108.3	92.5	42.1

improve the overall efficiency. Vehicle usage would increase with the decrease in the number of vehicles used to fulfill the same needs. In fact, mean daily distance travel by car would increase by 23.1 or 51.9 %, again for the 250 and 500 m scenarios, while time travelling (productive time) would increase from 1.2 h per day to 1.5 h (+23 %) or 1.8 h (+52 %) per day for the same scenarios. The time parked at home per car would decrease by 19 % for the 250 m scenario and 34 % for the 500 m scenario.

Discussion

Most cities now have to deal with a mounting increase in traffic and a limited space to "store" all these cars coming in every day. Considering the fact that cars are parked most of the time (Bates and Leibling 2012; Shoup 2011), sharing cars could be seen as another strategy to reduce the number of cars in cities, thereby reducing the need for road space devoted to parking.

Using data from a large survey covering the entire metropolitan area of Montreal, this study stresses the sizable reduction in the number of cars necessary to fulfill travel needs of car drivers on a typical weekday. The potential reduction of privately owned cars could reach 52 %.

Considering the recent decline in car use and ownership in many countries (Goodwin 2012), sharing cars also appears as a good avenue to improve access. For instance, in the United States, the proportion of households without a vehicle increased in 21 of the 30 cities examined between 2007 and 2012. In six of these cities (New York City, Washington D.C., Boston, Philadelphia, San Francisco and Baltimore), the proportion of households without a car was higher than 30 % in 2012 (Sivak 2014).

In many cities, we now assist at a deliberate attempt to reduce traffic through parking restrictions. In some places like Paris and Copenhagen, street space previously allocated to parking has been repurposed for bikesharing or tramway corridor access, while in other cities like Hamburg and Zurich, the existing parking supply has been capped (Kodransky and Hermann 2011). In the United States, the city of Boston now consider discouraging construction of new parking spaces in order to encourage the use of public transit and to devote more land and money to affordable housing and open spaces (Ross 2013).

According to Shoup (2011), parking is the single largest land use in cities. These impervious surfaces contribute to urban flooding, which is another reason why cities might want to restrict parking. Moreover, the opportunity cost of using space for parking is quite high in urban areas, since it reduces the space available for other functions such as housing units (Ben-Joseph 2012). Less cars in the city also means less parking requirements, thus reducing municipal developer costs and potentially increasing tax revenue from new housing developments and prompting more efficient land use (Shoup 2011). Reducing the required number of parking spaces could lead to substantial savings for municipal authorities, since the national average construction cost of each parking space in the U.S. is around $15,000 (Litman 2013).

Sharing cars would also alleviate the financial burden that comes with owning a car. In 2009, the share of household expenditures allocated to transportation was 20.6 % in Canada, 17.5 % in the United States and 15.2 % in the United Kingdom (U.S. Bureau of Labor Statistics 2012).

The recent advances in mobile technology combined with a cultural shift favoring access over ownership and the soaring price of gas make this option more and more realistic as time goes on. Considering the financial burden of car purchase and use for a household, it seems economically inefficient to invest so much for an equipment in use only 5 % of its lifespan.

Where and how carsharing will succeed? The issue has been addressed extensively by the Transportation Research Board in 2005 (Millard-Ball et al. 2005) but since, so many developments have occurred, making almost impossible to draw definitive conclusions other than the timely relevance of the topic. Nevertheless, according to research, neighborhood and transportation characteristics were found better predictors of carsharing success than individual demographics; carsharing is likely to flourish in areas characterized by low vehicle ownership rates and high proportions of one-person household (Celsor et al. 2007).

This research outputs performance indicators on the use of cars in cities as well as perspective regarding the steps that could be made if all cars were shared. The methodology could be improved in many ways. First, the dataset used for the estimation is a one-day trip diary. Hence, it is not possible to assess the travel needs during weekends or for long-distance trips. Households who own cars but do not use them during a typical weekday probably use them during the weekends. Travel demand for each weekday is not the same either. Also, the dataset does not allow estimating the current level of carsharing (informal or organised). The other limitation is related to the computation of figures for a typical weekday. A typical weekday is not representative of the day-to-day variability of travel behaviors nor seasonality. Therefore, the provided results need to be considered as a first deterministic estimation of a theoretical full-scale mutualization of cars, based on an average weekday of travel. Results do not necessarily correspond to the maximum number of shared cars that would be required on a continuous basis. Moreover, the final state of the computation, at the end of the day, was not assessed in regards to its ability to fulfill needs for another day. It is possible that more cars are required to meet the needs of the following day and so on. One research perspective related to this element would be to compute the scenarios for one full week using, again, observed data from week and week-end surveys (a week-end survey was conducted in 2008 in the Montreal Area). Given that the OD survey identifies the trip day, it is therefore possible to build several typical days (typical Monday, Tuesday…) by reweighting records (Verreault and Morency 2011). The other main limitation is related to the estimation of travel times. Even if GPS data were used to correct for travel times, it is possible that durations are still underestimated: this would increase the number of required cars (in the scenarios). Also, a step further will be to move to a simulation framework; it was not the approach chosen for this paper but it probably should be for upcoming researches. Finally, three assumptions related to consumer preferences underpin our estimation process: (1) travel demand is constant and will not change due to the fact that cars are shared instead of privately owned, (2) people have no objections to share their car and the available cars meet their travel needs and (3) there is no searching time for a vehicle. Taking into account the preferences of travelers with respect to shared cars as well as their response to changing transportation supply would provide more realistic assessment of the number of shared cars required to fulfill car driver trips; it seems like an important direction for future research.

Still, this research provides food for thoughts regarding the use of cars in metropolitan areas as well as the space dedicated to their use. But this is only the tip of the iceberg. Sharing cars is one step towards a more efficient use of this transportation mode, but increasing its occupancy is another solution that needs to be measured more precisely. Cars are currently moving with an important amount of empty seats. Increasing passenger density on our infrastructures is the way to improve efficiency of usage of collective infrastructures. Cars are not per se unsustainable: it is the way they are owned and used that will determine if they can be part of the set of transportation modes that will lead to better mobility opportunities for all and better sustainability for the collectivity.

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