Methodology of parking analysis

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ABSTRACT

Cities are faced with many challenges, in particular in relation to the mobility of people and the structure of land-use. Parking management, which makes the link between the fields of urban planning and transportation, is one of the crucial ways to meet these challenges. However, parking studies are a poorly covered area in transportation research. The main barrier to study parking is parking data availability.

In the Greater Montreal Area, data from origin-destination (OD) surveys are helpful in understanding typical travel behavior. These surveys have been conducted for forty years and provide useful data to describe and model various spatial-temporal features of daily mobility.

This research illustrates the use of OD survey data to develop indicators on parking spaces and use in a given area. This study confirms that the systematic processing of car driver trips from travel surveys allows developing vehicle accumulation profiles for various zones and, from these, derive theoretical parking capacities. This research provides an assessment of the quality of the estimation by comparing the estimations from OD survey to other sources of data, namely geographical data and field surveys.

The paper shows that parking capacity is subject to high variability and highlights that its assessment is quite complex and must take into account regulation data that modulates the availability of the raw parking capacity according to different days and hours of the day.

INTRODUCTION

The paradox of transportation vehicles is that they are most studied when they are the least used, i.e. when they are in motion, while they spend most of their time stationary or parked. For example, taking into account only the commute to work, which was measured to be on average 27 minutes by car in the six largest Canadian census metropolitan areas [1], cars are used less than 4 % of the day. Despite the importance of the phenomenon, "parking is the unstudied link between transportation and land use" as stated by Shoup [2] in his seminal work. There are several reasons to that, an essential one being the cost or difficulty to collect or have access to such data.

To address this need, this work illustrates the assessment of parking capacity of a given area using data collected in origin-destination (OD) household surveys. This paper uses a method developed by Morency et al. [3] based on vehicle accumulation profiles and proposes two methods to validate the estimates of parking capacity using data from two sources: several GIS sources and a field survey. It relies in particular on the latest OD survey conducted in the Greater Montreal Area in 2008.

The outline of this paper is as follows: after the introduction, we present a brief background, then the research methodology, the results of the application of the method to a borough of Montréal, and finally a conclusion with recommendations for future work.

BACKGROUND

In the field of Transportation, the phenomenon of parking, although essential, proves to be one of the least studied. Data collection in the field of parking studies is a major challenge. The diversity of parking types and the multiple variations of their vocations contribute to this difficulty. The Institute of Transportation Engineers presents several methods of data collection to analyze the parking spaces, their usages and their users [4]. Roess, Prasas and McShane provide a standard textbook approach to parking data collection and analysis [5].

Parking users have also been studied, for example the factors that may affect their choice of parking such as price and walking distance to the final destination. Weant and Levinson argue that the walking distance is competing with the cost of parking [6]. Habib et al. investigate the relationship between parking choice and activity-travel scheduling behaviour also using the 2008 OD survey data from Montreal [7]. They show that activity scheduling decisions of car drivers are significantly influenced by parking choice (being reflected in parking type and space availability). Several authors such as Bergman [8], Badland & al.[9], Cavaya & Baudouin [10], Coates [11], Darbéra [12], Engel-Yan & Passmore [13], Ferguson [14], Jakle & Sculle [15], Robert [16] and Willson [17] focus on less tangible areas of the parking problem, ranging from the perception of safety or comfort by the users of parking spaces, the impacts of laws, regulations and parking policies on communities and modal choices [18].

Shoup supports that for users of the parking spaces, the perception of the comfort of the sidewalk, between the parking area and the final destination, increases the tolerated walking distance [19]. In that line of thought, Litman advocates a new paradigm for parking policy which takes into account more urban planning concepts such as the integration of parking spaces in their neighborhoods [20].

Regarding the impact of laws and regulations, most studies argue for a greater tightening of laws governing parking. Marsden conducted a literature review that contradicts the theory that fewer parking spaces in business centers and retail areas contribute to their impoverishment [21]. Shoup highlights the inequalities between car drivers and people using other modes vis-à-vis the regulations and parking policies in several North American cities [2]. He argues that subsidy policies and free parking lead to increases in costs of goods and services, shared by all citizens, including those who do not use cars. Meanwhile, Litman, demonstrates how laws governing the parking spaces requirement have an impact on housing affordability [22].

Despite the diversity of areas for parking, most authors agree on the fact that more accurate parking data would contribute to better decision making.

This work builds upon the research by Morency et al. [3] and Tong et al. [23]. These authors have proposed a methodology to estimate parking capacity in various areas using travel survey data. Their method relies on the spatial-temporal monitoring of cars in the region using declared car driver trips. With their 5 % sampling, the Montreal travel surveys have sufficient data to allow for specific analysis. The method also relies on declared information on the type of parking space used at the destination. It is hence possible to cumulate cars in space throughout a typical day and to estimate a theoretical parking capacity using the maximum number of cars simultaneously parked in an area.

METHODOLOGY

Concept

As mentioned earlier, the method to evaluate the use of parking spaces from OD survey data was first developed by Tong et al. [23] and Morency et al [3] for the Montreal area. Car driver trips observed in the travel survey are sequentially processed in order to follow the movement of cars in time and space. This allows analysing the use of parking spaces during a typical day of the fall period during which the survey was conducted. More details on the data sources are provided later. This work relies on the same method to estimate the accumulation of parked vehicles in the areas under study during the day. The theoretical parking capacity of an area is the maximum accumulation observed during the day.

The validation approach proposed in this work combines several methods, some of which are inspired by well-known traditional methods (field survey methods, conventional dimensions, etc.), while others rely on newer tools (Google Street View, OpenStreetMap, and other public sources of geographic information). For a given area under study; it is composed of three main steps presented in Figure 1:

1. The first step is to estimate, using car trips from the OD survey, the accumulation of vehicles and the theoretical capacity for the area
2. The second step is to determine the raw parking capacity (without regulations) and the actual capacity (taking into account the regulation information) based on a field survey
3. The third step is to compare the data obtained in the first two steps to determine the difference between the actual parking capacity and the theoretical capacity.

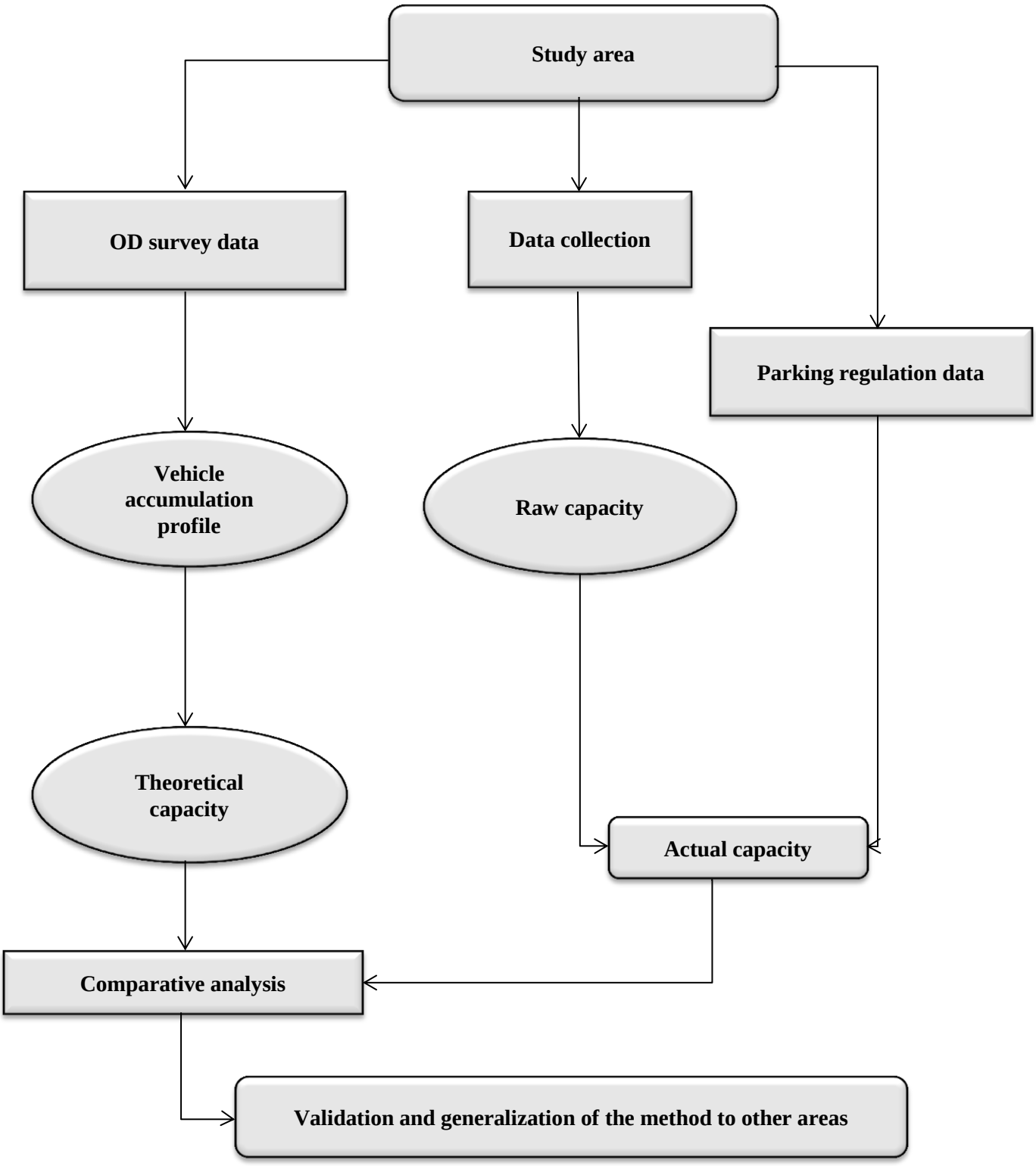

Figure 1 Methodology for the validation of the parking capacity estimations.

Data Sources

The main source of data for this study is the Origin-Destination (OD) survey conducted in the Montreal region in 2008 (direct source); other sources of data, such as public data from OpenStreetMap and data collected in a few districts are the results of field observations (source of proxy data). Observational data collected during this research, as well as data obtained through partners, were used to supplement or verify the results derived from the OD survey data.

Direct source: 2008 Origin-Destination survey of the Montreal Area

OD surveys are regularly conducted in the Montreal area; they are descriptive surveys that aim to provide a picture of the characteristics of individual travel (origin, destination, modes, trip purposes ...) and demographic variables (age, gender, income ...). These telephone interviews reach around 4 to 5 % of the people of all occupied private households in the Greater Metropolitan Area of Montreal [24]. They have been carried out at intervals of five years for over 40 years.

Like other OD surveys, the 2008 OD survey was conducted during the autumn of 2008, from September 3rd to December 18th. It covers an area of 8200 km2, including 141 municipalities. 319900 trips were recorded from 66100 households consisting of 156 700 people. Only the movements of individuals over 4 years were recorded and only the trips done during working days of the week (Monday to Friday) are collected [24]. Telephone surveys were conducted using CATI (Computer Assisted Interviewing Count) which allows pollsters to validate certain information in real time in order to reduce errors.

The parking type classification used in this study follows the OD survey's classification. Parking is classified according to the monetary conditions linked to it (free, paying or subsidized) and by its location (on-street, outdoor, interior). When the type is not defined, it's classified in the indeterminate category. In this study, all the parking spaces that are neither on a curb side nor inside a building are considered as outdoor.

Indirect source: OpenStreetMap, Google Street View and other GIS

Some analyzes in this research required geographic data such as the lengths of streets and areas of outdoor parking spaces. Obtaining this data can be complicated, especially as it is managed by several different organizations (city, district, agency, companies...).

Some free services such as OpenStreetMap and Google Street View allow access to relevant geographic data. Thus, OpenStreetMap was used to find the lengths of streets and area of outdoor parking spaces, while Google Street View was used to evaluate the data obtained from OpenStreetMap.

Other data sources

In addition to OD survey and geographic data, complementary data was obtained through partners to validate and supplement the other data sources. For example, a file of the complete inventory of outdoor parking in the borough of Plateau Mont-Royal was used to validate the location of these types of parking.

Capacity estimation

As presented in Figure 1, the parking capacity is determined by two methods using two different data sources for the same area. OD survey data will determine the vehicles accumulation profile (VAP) and the theoretical parking capacity, while field data collection and the use of geographic data will allow to determine the raw and actual parking capacity: the difference between these two should be related to parking regulation.

Capacity determination from OD survey data

The vehicle accumulation profile (VAP) Determining the vehicle accumulation profile follows the method proposed by Morency et al [3]. This allows to determine, for a given time interval, the amount of

parked vehicles in a given area (in our case, a borough). The accumulation of vehicles in an area follows the principle of arrivals and departures of vehicles. Using data from OD surveys, it is possible to determine the vehicle accumulation profile by type of parking, by trip purpose and by region of origin of the movement (or by region of domicile of the person making the trip) for a typical day or weekday of fall.

Theoretical parking capacity (TPC) Theoretical parking capacity is directly derived from VAP and corresponds to the maximum value over the day. It is also possible to observe the maximum value for each hour of the day.

Estimating the capacity from the field data collection

Estimation of raw parking capacity The estimation of raw parking capacity must be done separately for on-street and outdoor parking. The raw on-street parking capacity is determined by calculating the number of parking spaces for each area. The number of parking spaces is measured by dividing the length of street where parking is allowed by the average length of a car. The following formula is used:

$$N_{spaces} = \frac{L - [(b * 5) + (e * 3) + (Tc * 15) + (i * 7)]}{a}$$

Where:

L is the average length of the stretch of road (m)

b is the number of terminal-fountain

e is the number of driveways

Tc is the number of bus stops

i is the number of spaces where there is a strict prohibition of parking

a is the average space (linear) occupied by a parked car (m)

The constants used in this formula are the length (in meters) of street lost by each type of permanent equipment. Thus, each terminal, driveway, bus stop and forbidden space reduces respectively the length of street available for parking by 5 m, 3 m, 15 m and 7 m. The typical values found for *a* in this study varies depending of the on-street parking angle, from 7 m for the parallel parking, to 4 m for 45^o parking and 3 m for 90^o parking. However, these constants may vary in different contexts. The field survey should assist in finding more realistic values.

Outdoor parking areas (excluding aisles) are divided by the area required for a vehicle parking and parking manoeuvers. The following general formula is used:

$$N_{spaces} = \frac{S - [\sum_{i=1}^{n}(L_i * l_i)]}{a + \lambda}$$

Where:

S is the area of the parking area (m^2)

n is the number of aisles

L_i is the length of aile *i* (m)

l_i is the width of aisle *i* (m)

a is the average area occupied by a parked car (m^2)

λ is the necessary space around the vehicle for parking manoeuvers

The average values used for *a* and $a+\lambda$ in this study are 21 m^2 and 25 m^2.

The actual capacity of parking: It can be obtained by combining the raw capacity and the regulation data. Regulation data is necessary to provide an accurate measure of actual parking in a given area. An important part of this research was to develop a data collection method to collect reliable data, which could be compared to the parking estimates based on OD survey data.

Thus, we proposed two methods to gather the necessary data: field survey and public geographic information systems (GIS). Both methods allow applying the previously presented formulas for determining the number of parking spaces.

Data collection methods

Field survey

A field survey consists in going in the field (in the chosen sector) to conduct a comprehensive survey of data related to the calculation of parking capacity. Data collection by field survey is made for two types of parking, for on-street and outdoor parking.

- On-street parking data collection: all information related to parking are noted, among others the lengths of street sections, the number of permanent equipment (fire hydrants, driveways, bus stops , etc..), the information provided by regulatory signs (including the strict prohibitions of parking at any time) and parking availability by type (public, private, reserved, paid, free, funded ...)
- Outdoor parking data collection: information is collected about the areas of parking spaces, the types of parking available and the information provided by the regulation governing the parking (which has less variation than for on-street parking).

The advantage of this method is that it is very accurate and provides detailed information. However, in addition to being expensive and dependent on weather constraints, this method has many logistical constraints, such as:

- The determination of the lengths of segments during field trips is relatively easy. However, this requires the use of measurement instruments, which can be cumbersome. Because of the large amount of information to be collected in this study, the choice was made to determine the distance from a geographic information system (GIS) using OpenStreetMap.
- Parking regulation signs are difficult to collect, particularly because of the large number of sign and the large amount of information contained in each. However, the information they provide are necessary for the determination of the actual supply of parking.

Data extraction from geographic information system (GIS)

This method does not require a field trip: it uses GIS layers and tools to extract data. Recent advances in the world of geographic information helps to provide a lot of public data.

Data is collected in GIS by going (virtually) in every street, alley and other parking spaces available and by identifying any data related to the calculation of the parking supply, as done in field surveys. As in field surveys, it is done for both on-street and outdoor parking. Figure 2 shows an example of using GIS (Google Maps and Street View in this case) for data collection purpose.

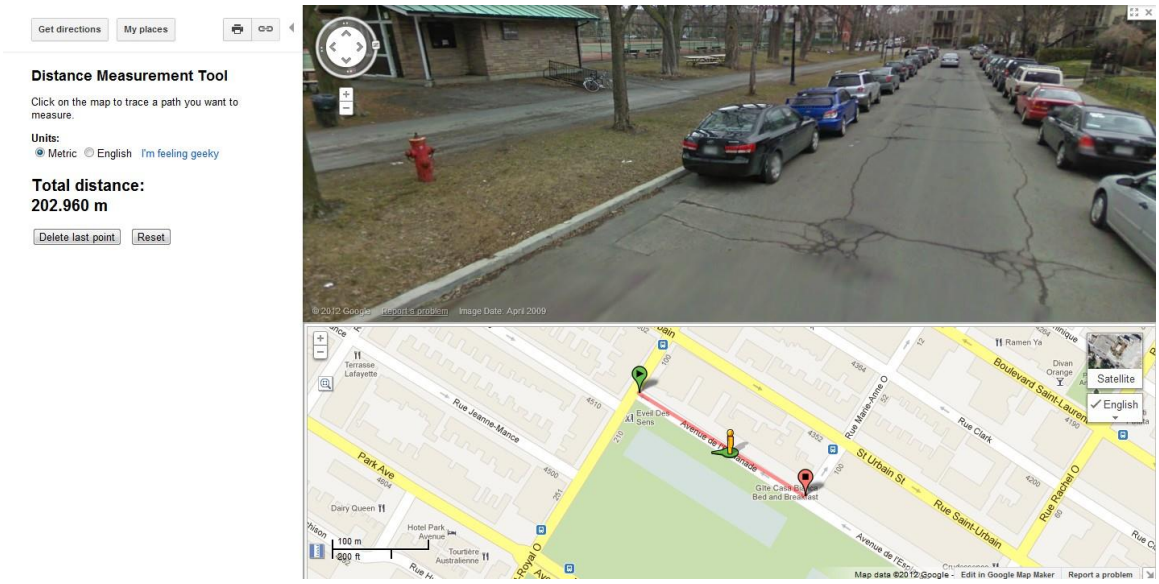

Figure 2 : Distances and permanent equipment data collection method (Google Street View).

Compared to the previous method, this method has several advantages; such as:

- it is faster and cheaper, because it does not require people on the ground.
- It does not depend on the weather.
- It allows a better overview, using the zooming tools.

The disadvantages are associated with the limits of the technology used, and several types of errors can by made, for example:

- It is possible that an object is hidden by another (a fire hydrant or a driveway can be hidden by a truck).
- The distance measuring tool integrated in the software used in this method is not very accurate, and its accuracy depends on the zoom level of the studied area.
- The calculation of the area of parking with this method is complex and unreliable, because this tool does not measure areas. Cadastral data are best suited for providing this information, but was not available for this project and therefore the use of public data such as OpenStreetMap data has been favored.

RESULTS

The study area

A central neighborhood within the Plateau Mont-Royal borough is taken as a sample, to illustrate our approach. This quadrangle was chosen because it has mixed levels of zoning and types of streets with multiple lanes. The study area is bordered by two large regional parks to the east and the west, with mixed land-use (residential, commercial, institutions and parks). The selected area has a dimension of 1200 meters by 650 meters. According to data from the OD survey of 2008, it gathers 2048 households consisting of 3286 people. The number of cars owned by residents is 1190 from which some 78% (or 933) have not moved during the day of observation.

Accumulation profiles and theoretical capacity

The theoretical capacity derived from the OD survey for the area is approximately 2783 parking spaces, distributed as follows

- 933 vehicles remained parked all day, on-street;
- 780 on-street parking spaces;
- 240 spaces in parking garages (Interior parking) ;
- 690 outdoor parking spaces;
- 140 parking spaces for which type was not declared (indeterminate).

For this zone, the maximum number of cars simultaneously parked is reached at 13h45. The peak of parking for work purpose is reached at 10h45, while that for leisure purpose is reached at 21h15.

Free parking and on-street parking are the most popular parking categories, while work purpose is the reason most cited by people as trip purpose, followed by leisure. The following Table 1 and Table 2 summarize the distributions of parking occupancies, while Figure 3 and Figure 4 are the graphic representation.

Table 1 Distribution of capacity occupancy based on parking type in the study area.

		Types				
		On-street	**Interior**	**Outdoor**	**Indeter.**	**Total**
Types	**Free**	32,80%	10,60%	16,10%	0,00%	59,40%
	Paying	9,30%	1,10%	6,90%	0,00%	17,20%
	Subsid.	0,00%	1,30%	14,50%	0,00%	15,80%
	Indeter.	0,00%	0,00%	0,00%	7,50%	7,50%
	Total	42,00%	13,00%	37,50%	7,50%	

Table 2 Distribution of parking occupancy based on trip purpose in the study area.

Reason	%
Work	54,00%
Study	1,20%
Leisure	27,10%
Shopping	2,40%
Other	5,10%
Home	10,20%

The following Figure 3 and Figure 4 show the graphs of VAP, by type of parking, obtained for the study area. The maximum of the VAP in each category is the theoretical parking capacity in this category. We can see that the type of parking most used is free on-street. Subsidized outside and subsidized interior which expand from 6h30 to 18h30 correspond to office working hours. The variations of free on-street and free outside parking can be expected: for example the peak in the usage of those two parking type is during the shopping hours, the lunch, dinner and other leisure hours.

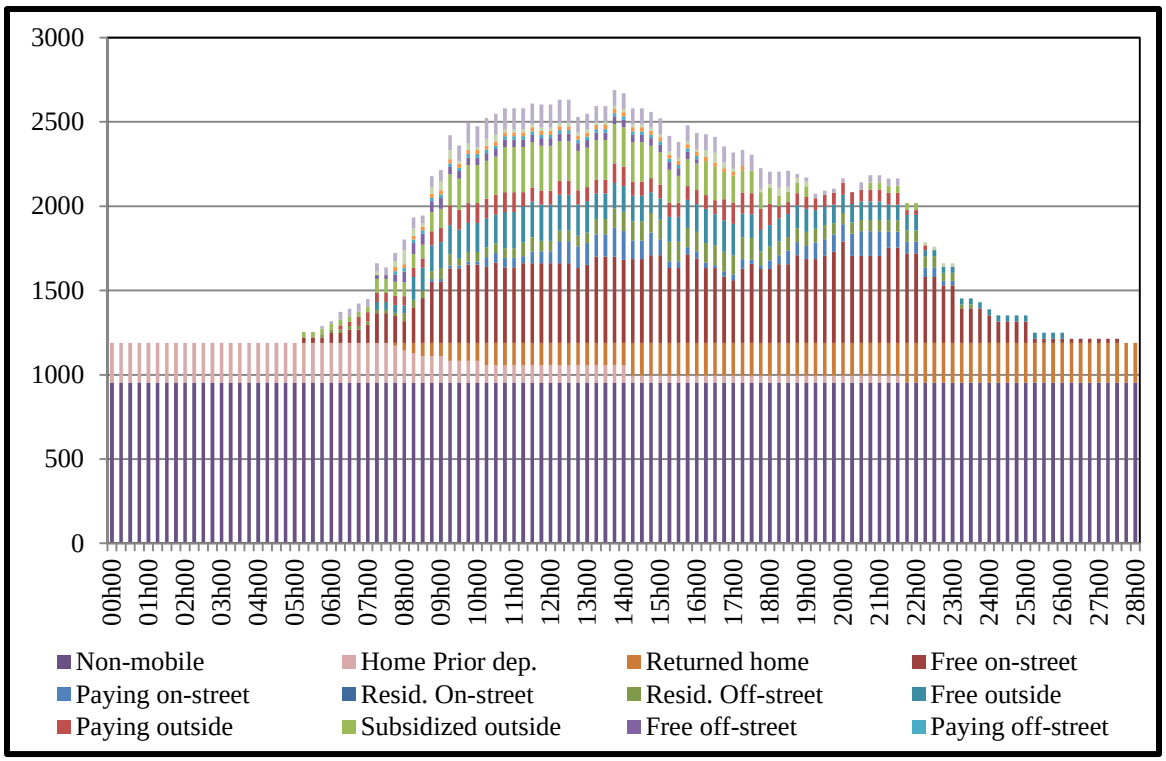

Figure 3 VAP by type of parking in the study area.

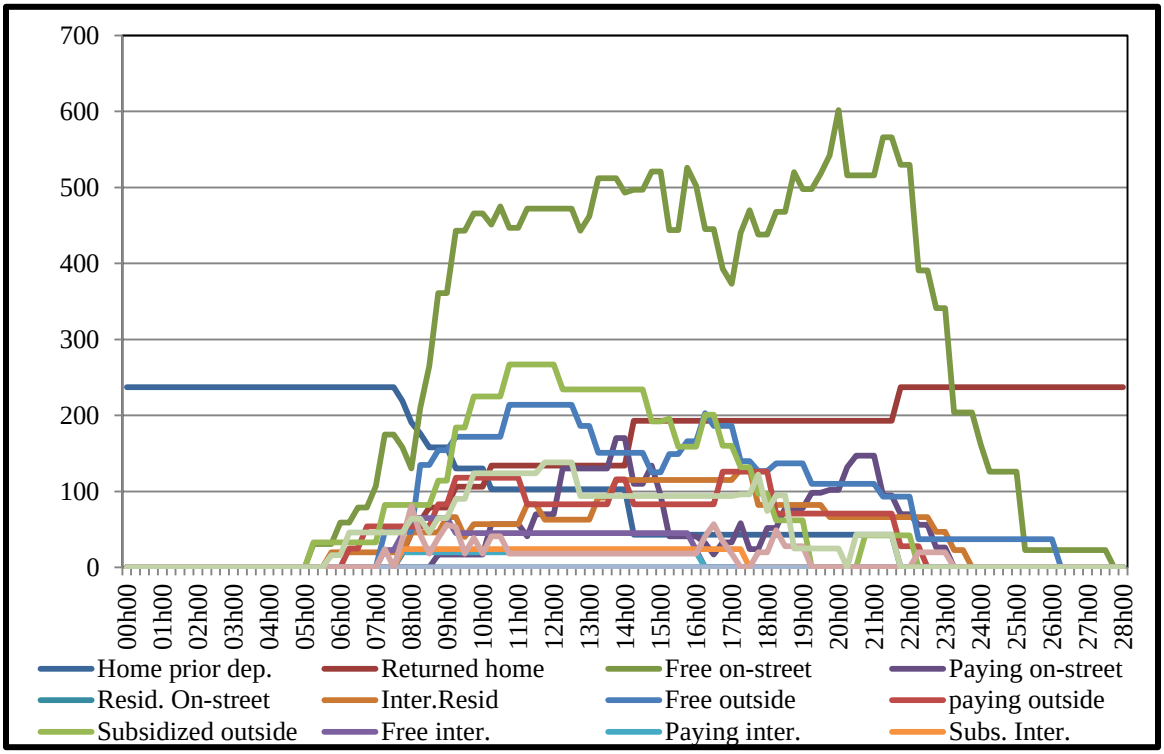

Figure 4 TPC of different types of parking in the study area, without the non-mobile vehicles.

Validation of raw capacity in the study area

Using the field and GIS data, collected during the 2nd week of august 2011 by the first author, raw parking capacity is estimated as 4941 parking spaces, of which 3994 are on street and 697 are in outdoor parking lots. Indoor parking, estimated at 250 spaces, was not considered in this analysis, particularly because of the difficulty in confirming the actual purpose of interior parking spaces.

On-street parking

For on-street parking, the theoretical capacity extracted from the VAP, is smaller than the raw capacity obtained from the field survey. This is because, for on-street parking, parking regulations have a strong influence on the real capacity.

Our observations allowed estimating the raw capacity at about 4941 parking spaces, from which 3994 were on-street parking spaces. We consider that the estimated total on-street parking spaces derived from the OD survey data is 2053 vehicles, by adding the majority of the 140 vehicles classified in the indeterminate category to the 780 on-street parking spaces and the 933 stationary vehicles parked on-street. On-street parking is more likely to be classified in the indeterminate type due to the high effect of parking regulation variations on them. By comparing the two estimations, we observe that:

- In the study area, on-street parking derived from travel surveys data accounts for about 40 % of total raw parking capacities.
- The non-mobile on-street vehicles accounts for about 20 % of total raw parking capacities

Outdoor parking

Regarding the raw capacity for outdoor parking lots, the difference with the theoretical capacity is negligible. In fact, the raw capacity of outdoor parking was estimated at 697 parking spaces, while the theoretical capacity of parking outdoor was estimated at 690. These results are more similar than for on-street parking, because parking regulations that apply to outdoor parking lots are simpler. Also, the outdoor parking lots are less likely to be declared in the indeterminate type, especially because of the fact that there is little change in regulations governing outdoor parking.

The effect of parking regulation on parking capacity

In order to evaluate the parking capacities variations, caused by parking regulations changes, we selected a section of a street for detailed analysis. The idea is to apply the parking regulation data to the raw capacity to determine the capacity fluctuations induced by changes in regulation.

Description of the street section

Given the strong influence of parking regulations on on-street parking capacity, we selected a street section on which the only type of parking is the on-street parking. The section studied is a 635 meters one-way street with parking spaces on both sides.

Capacities and their variations

In general, parking regulations vary according to parking categories (reserved for the residents and unrestricted), the hour, the day and the season. For this section of the street, if we create a group based on the uniformity of parking regulations, according to the day, we would have three groups of days: Mondays, Tuesdays and Thursdays will constitute a first group while Wednesdays and Fridays will each be representing a group. If we apply the same logic to hours in order to find blocks of hours with homogeneous regulations, we have the five following blocks from 23h00 to 9h00; from 9h00 to 12h00; from 12h00 to 13h00; from 13h00 to 17h00; and from 17h00 to 23h00.

The data collected in the field allows us to evaluate the raw capacity of the studied section at 210 parking spaces. Taking into account regulation, the capacity thus varies by category of day, hour of the

day and parking category and is presented in Table and Figure 5. For several days between 12h00 and 13h00, the number of available parking spaces falls. That could be explained by parking regulations anticipating roadwork such as snow collection and other infrastructure maintenance.

In the parking category, the sum of the unrestricted and reserved parking spaces is the available parking spaces in a given time: parking is sometimes banned in up to 33 % of all spaces on Friday at noon.

Table 3 Parking capacity variation in the studied street section by day, time and category.

	Capacities on the street section under study								
	Monday, Tuesday, Thursday			Wednesday			Friday		
	Unrestricted	**Reserved**	**Available**	**Unrestricted**	**Reserved**	**Available**	**Unrestricted**	**Reserved**	**Available**
Before 9h00	99%	1%	100%	99%	1%	100%	99%	1%	100%
9h00-12h00	66%	34%	100%	66%	34%	100%	66%	34%	100%
12h00-13h00	66%	34%	100%	38%	34%	72%	33%	34%	67%
13h00-17h00	66%	34%	100%	66%	34%	100%	66%	34%	100%
17h00-23h00	60%	40%	100%	60%	40%	100%	60%	40%	100%
After 23h00	99%	1%	100%	99%	1%	100%	99%	1%	100%

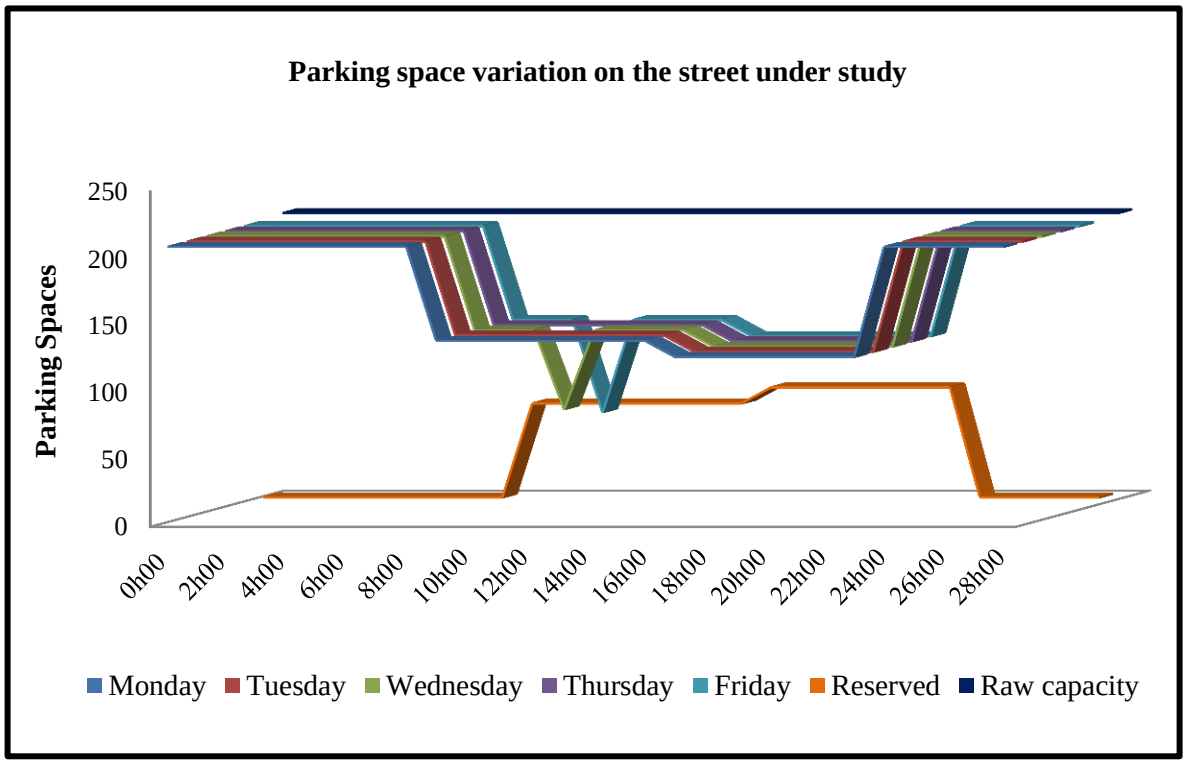

Figure 5 : Variation of parking spaces on the street section under study (note that the number of reserved parking spaces does not depend on the day).

CONCLUSION

This study was conducted to lay the foundations of a methodology for parking analysis. In our journey, we were given the opportunity to contribute to several areas in relation to parking; among others we can mention that:

- We tested a method for determining the accumulation profiles of vehicles and parking capacity in the districts from data origin-destination surveys. This method allowed us to use data from a survey that was not designed for parking study.
- In this research, we have also proposed a method for determining the parking capacity of an area. The methods of collecting and processing data introduced in this study could help to improve knowledge in the field of transport in general and especially parking

This work thus demonstrates that it is possible to estimate the parking capacity from OD survey data. The study also shows that regulations are necessary to determine the amount of on-street parking, since it was found that the on-street parking capacity estimated from the OD survey data was equivalent to about 2/5 of the raw on-street parking capacity measured in the field. Since this study deals with only a small area, it is not possible to generalise this result: we do not know whether this 2/5 ratio applies in other Montreal boroughs and in other cities. In future work, the method will be applied to other areas in order to validate the method and develop more robust processes. This study is a first step in evaluating a method for parking study. The main task will be to collect and better integrate data from parking regulations to the model presented in this study.

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