GEODEMOGRAPHIC ANALYSIS AROUND RAIL STATIONS TO MEASURE URBAN DEVELOPMENT OPPORTUNITIES

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ABSTRACT

Increasing density in the surroundings of important transit nodes is one of the strategies that were approved in the Montreal Area to promote sustainable mobility. With a new land-use and development plan recently approved involving density targets near suburban rail stations, it is relevant to provide insights into the way these stations are currently used, to circumscribe catchment areas and to estimate both the potential of walking as access mode and impacts of increased residential density. This research relies on on-board travel surveys conducted among the suburban rail lines in the fall of 2008. It proposes a description of the use of suburban rail in Montreal as well as a methodology based on access desire line density to circumscribe catchment areas of stations. Typologies of stations are proposed based on boarding rates, access modal split and attractivity zones. Threshold distances i.e. those that 80% of users are willing to travel are also compared by mode, rail line and population segment. Potential of walking is also estimated in walk catchment areas and could rise by 9% if current motorised access in walk catchment areas were transferred to walking.

Keywords: suburban rail, demographic analysis, attractivity zones, modal share

INTRODUCTION

With the increasing urge of government to find ways to reduce the negative impacts of transportation, strategies and policies to promote greener ways to travel have become central in transportation plans. With the clear understanding of the intertwined interactions between travel behaviours and land-use development, strategies are also focusing on urban development. Transit-oriented development and density targets are listed as strategies to reduce dependency on private car and promote the use of alternative modes of transportation.

In the Montreal Region, a metropolitan plan of land use and development (PMAD) was recently adopted (CMM, 2011). It is structured around three main orientations, two of them directly related to the interactions between urban development and travel behaviors:

1. Creating sustainable neighborhoods;
2. A region with determinant and efficient transportation networks and equipments.

Targets of urban density are identified for various neighborhoods, namely in the surroundings of important transit nodes. The aim is to cluster people in places where there are more travel options and where the private car is not necessarily the most competitive one.

In this context, it was relevant to better understand the current surroundings of rail stations in order to assess development potentials. With respect to access to transit, Moniruzzaman and Páez (2012) distinguish between two types of accessibility :

- Access to transit infrastructures and service relates to the facility with which people can reach bus stops or subway / rail stations;
- Access by transit estimates the possibility offered by the transit system to reach activity locations.

The method we apply in this research relates to the first definition. Actually, this research focuses on suburban rail stations and the urban development opportunities in their neighborhoods. Its main objective is to measure, using combined data on travel, population and transportation network, the current travel behaviours of people accessing the transit network using rail stations as well as the potential of active modes in the catchment areas. The paper is a follow-up on a previous research conducted around subway stations (Páez *et al.*, 2012).

The paper is organised as follows: first, some contextual elements are provided, followed by a description of the general methodology including study case and information system description. Some key facts regarding transit use in Montreal are then provided. The following sections focus on the analysis of rail usage and definition of catchment areas of stations by mode. Estimation of such zones for walk only allows estimating the potential of walking to access rail stations. Impacts of increased density in the surrounding of stations is also estimated.

CONTEXT

In 2011, the Montreal Metropolitan Community proposed a metropolitan plan on land-use and development (PMAD). This plan is one of the first attempts to clearly address the land-use contribution to travel behaviors in the region. It proposes some elements of an integrated understanding of the interactions between land-use decisions and travel opportunities and choices. This plan was adopted by 82 cities of the Montreal metropolitan area and aims at addressing three main challenges faced by the Greater Montreal Area (GMA):

1. Challenge 1: land-use. The GMA needs to identify the type of land-use to privilege in order to welcome the forecasted growth in population in the next twenty years.

2. Challenge 2: transportation. The GMA needs to optimise and develop current and projected transportation networks in order to support the growth in population and contribute to the consolidation of land-use.

3. Challenge 3: environment. The GMA needs to protect and value its natural and constructed assets in order to improve the attractivity of the region.

Our study is mainly related to the first challenge for which the CMM has proposed the strategy of concentrating urban development in the immediate surrounding of important transit nodes. This objective is structured around three criteria's:

1. Localise TOD around structuring transit access point in order to concentrate 40% of the new households;

2. Set minimum density criteria's for these TOD (dwellings per ha);

3. Implement TODs.

Principles of TOD

Transportation infrastructures deeply influence land-use and vice-versa. Car-oriented development facilitates urban sprawl and dispersed development increases dependency towards private cars. Contrarily, urban development led by transit and alternative modes of transport improves the efficiency in land usage and promotes more sustainable transportation behaviors (Lin and Gau, 2006).

Cervero et al. (2002) propose a literature review on transit-oriented development in the United States. They note that even if the definition of TOD varies among authors, most of then share similar notions: mixed-used development, well covered by transit supply and that promotes the use of sustainable modes. The concept of high density near transit nodes that facilitates the use of transit is often mentioned as a key to more sustainable behaviours. According to Cervero and Kockelman (1997), land-use can influence transportation demand through three main levers named the 3Ds: density, diversity and design. Reinforcing density also helps increase transit ridership and improve accessibility by making it easier to access by walking or cycling.

METHODOLOGY

Study case

Montreal is the largest metropolitan area in the Quebec province (with some 50% of the population) and the second largest in Canada (after Toronto). Its transit share is one of the highest in North-America with approximately 20% of daily trips relying on transit and more than 60% for trips with a destination in the central business district.

In addition to being an interesting region with respect to culture, higher education and innovation, it is also recognised for its rich sets of data on travel habits that can feed various researches and analysis on the domain.

Transit network

The transit system is structured around 5 subway lines (68 stations) mainly providing services on the Montreal Island. Five suburban rail lines provide services from the central core to suburban areas. The scale and level of service of rail has been improving since the creation of a new metropolitan authority in 1996. Since then, three lines were sequentially added to the initial network and improved schedules were implemented. The current network is presented in Figure 1 that also shows a sixth rail line which is under implementation.

Figure 1. Metropolitan suburban rail network (source: http://www.amt.qc.ca/uploadedImages/AMT/Site_Usager/Train/BlocDroit/Train_Map_Agrandi.jpg)

Information system

The research relies on various sets of data.

On-board surveys

The Montreal metropolitan agency conducts on-board travel survey every year on the suburban rail network. Paper questionnaires are distributed at stations during AM peak period and can either be filled during the trip or sent back by mail. This research relies on the 2008 on-board surveys since it is the latest for which geocodification for all spatial locations was available. The overall response rate for the survey is 72.9%. This is the proportion between completed questionnaires and number of people who boarded the train during the survey period.

These surveys are typically conducted in September since it is one of the busiest periods of the year. Questions regarding the trip that is currently performed by the traveller are asked. They focus on home location, traveller attributes, access and egress modes as well as origin and destination points.

Census data

Demographic data from the Canadian Census are also included in the research to characterise neighborhoods of stations. Data are available at the dissemination area (DA) level. As explained by Statistics Canada, "*dissemination areas are uniform in terms of population size, which is targeted from 400 to 700 persons to avoid data suppression*"[1].

Transit and road networks

Other sets of data are involved in the research:

- Transit file: geographic file of the rail network is used to describe the geometry of the lines, its level of service as well as parking availability. This was made available by the operator but all the information is publicly available on its website;
- Road network file: the Road Network File from Statistics Canada[2] is used to estimate indicators in the surroundings of stations.

Analytical procedure

Figure 2 summarises the analytical procedure of this research. It mainly relies on the processing of trips observed in the on-board surveys. On the one hand, demographic features of the rail users are described both from a network-based perspective (all lines combined) and from a station-based perspective (station by station). On the other hand, access modes are examined also globally and by station. These two elements are then combined to feed the development of attraction zones (or catchment areas) and understand mode selection. A specific application to walking is then performed to estimate the potential of walking to access the rail network.

[1] http://www12.statcan.gc.ca/census-recensement/2006/ref/dict/geo021a-eng.cfm
[2] http://geodepot.statcan.gc.ca/2006/040120011618150421032019/1814062006_05-eng.jsp

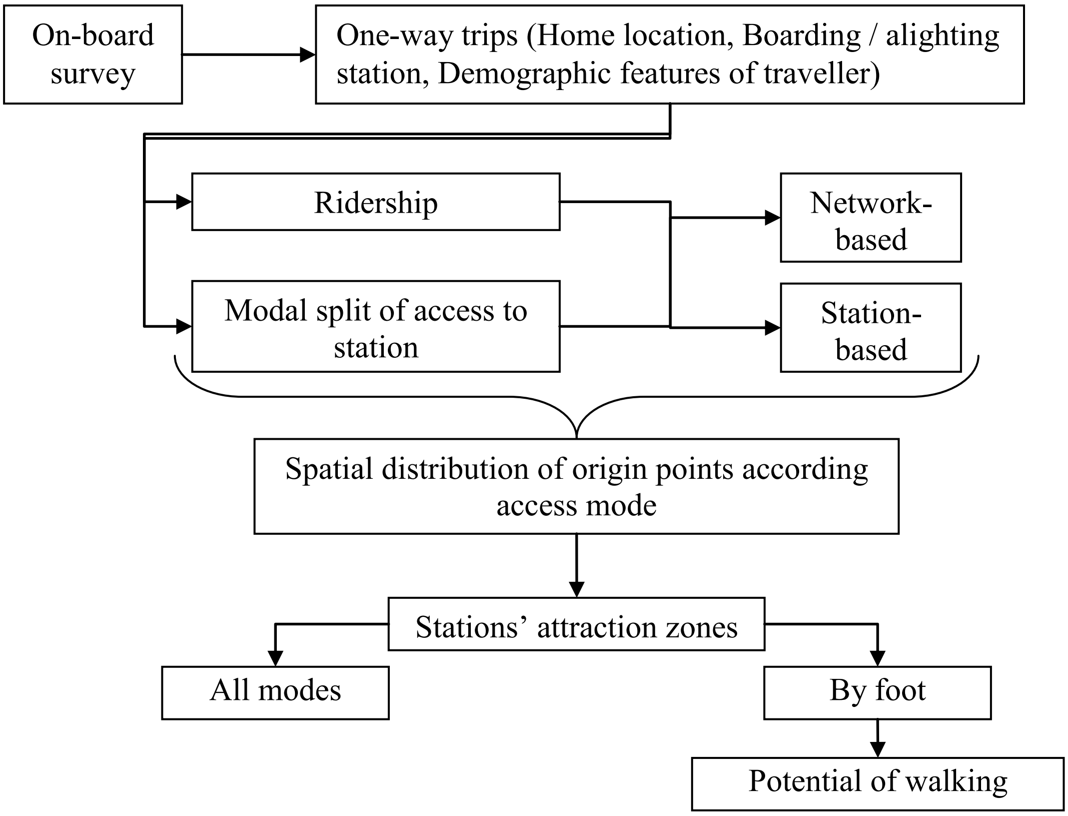

Figure 2. Analytical procedure

TRANSIT USE IN MONTREAL: KEY FACTS

In 2008, an important increase in transit use was observed: ridership increased by 4.1% in one year, while mean yearly increases were around 1.6% for the previous 10 years. In the case of suburban rail, annual ridership reached 15.7 millions (2008), an increase of 4% in comparison with 2007 (AMT, 2009). Factors such as increasing congestion and oil price volatility partially explain this increase.

Daily ridership

As estimated by 2008 on-board surveys, daily ridership during AM peak period is higher than 33 000 people. Montreal central business district is without a doubt the number one destination for suburban rail users with some 70% of the AM period trips egressing in this zone. CBD and centre of the Montreal Island account for up to 90% of all suburban rail destinations.

Trip purpose

In the AM peak period, suburban rail is mainly used for work purpose (79.9% of trips) and study (18.6%).

Boarding ridership

In our study, a lot of attention is set on access modes to stations. In this context, we estimate stations' ridership as the number of users who board at each station during the observation period (AM peak).

The share of boarding ridership varies a lot throughout the network. Some stations attract up to 10% of total ridership while others only account for less than 0.1%. Figure 3 presents the number of boardings at each station in the morning. The height of the circle polygon is proportional to the number of boardings and colour emphasises the differences. It is obvious that one of the lines is responsible for a high proportion of the boardings: this line is one of the two that have been operating for a long time and was fully modernised in 1993. Table 1 provides additional details with respect to ridership of each rail line. The dominant line is supporting more than 44% of the boardings during the AM peak period.

Table 1. Key facts on ridership at each station

Suburban rail line	Number of stations	Number of users	Proportion of regional users
VH	19	8 340	24.9%
DM	12	14 880	44.5%
BL	11	5 290	15.8%
SH	7	3 560	10.6%
CA	8	1 390	4.2%

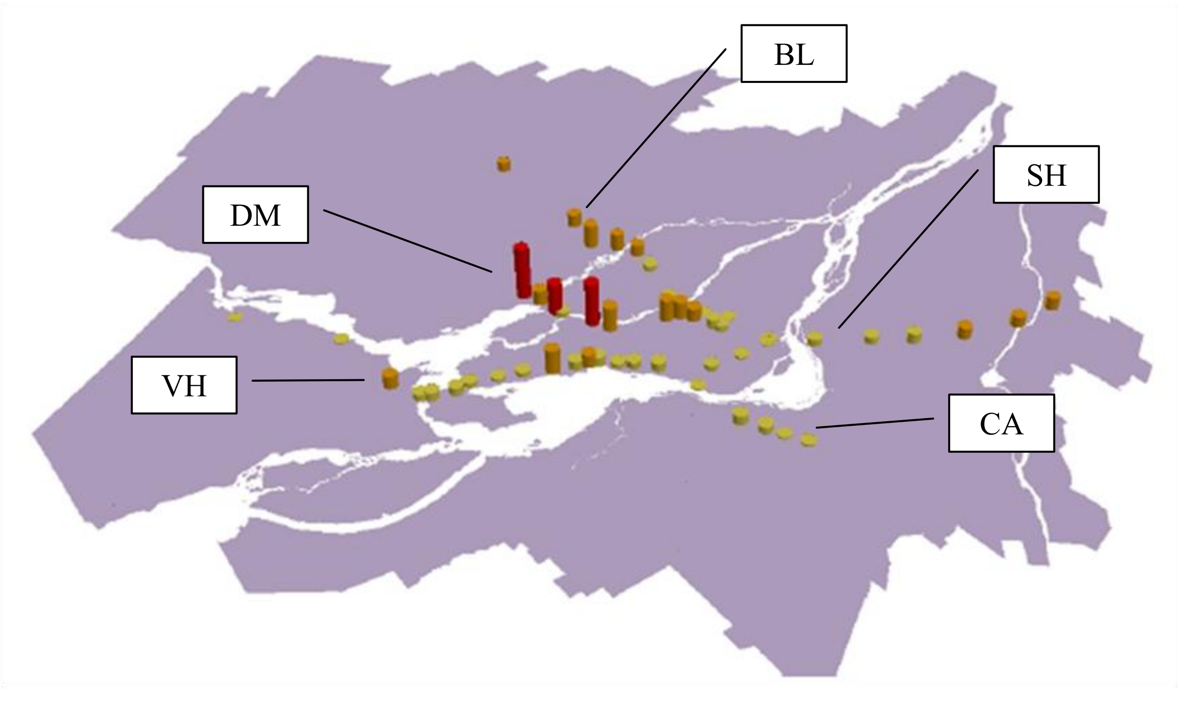

Figure 3. Spatial representation of boardings at stations during the AM peak period

Boarding rate

In order to categorise stations, a boarding rate is estimated. This rate corresponds to the proportion of boardings over the total number of movements at a station, during the AM period (boardings + alightings). Using this rate, three types of stations are identified:

- Boarding stations with rates over 80%;
- Mixed stations with rates between 20-80%;
- Alighting stations with rates below 20%.

During the AM peak period, we observe a high dominance of boarding stations with 75% of the stations having boarding rates over 80%, 13.5% categorised as alighting stations and the residual (11,5%) as mixed stations. With such statistics, it is obvious that the suburban rail system mostly provides service to commuters in the peak direction.

Age groups

Figure 4 presents the composition of both population and suburban rail users according to main age groups. We see that the 25-54 years old account for almost 70% of the rail users but less than half in the population. Two main population segments make use of the rail: 25-54 years old and 15-24 years old.

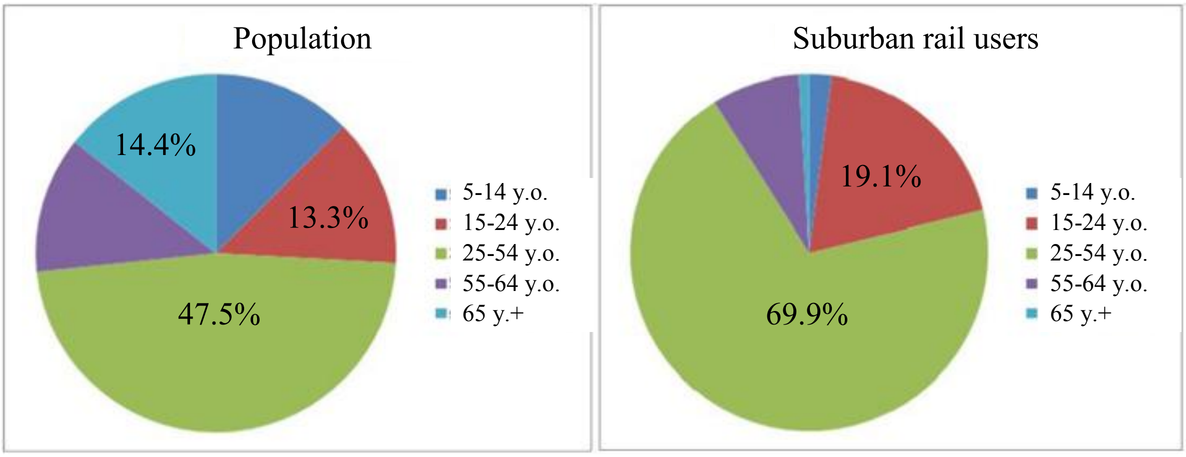

Figure 4. Comparison between demographic composition of the population and of rail users

ACCESS TO RAIL STATIONS

Access to rail stations is a critical step in the modelling of both route choice and modal choice in an area where suburban rails compete with other transit modes as well as private car. In Montreal, the role of car in the access to suburban rail stations has been increasing with the widespreading of the network in the last decade.

Modal split

Access mode to rail station is analysed using the on-board survey data. Results shown in Figure 5 confirm our previous statement regarding the importance of car to access rail station. In 2008, more than 65% of all access are made by car (driver + passenger), while walking is used for 20% of accessing trips. Less than 12% of the trips rely on transit for access. There is certainly room for improved access by transit to reduce pressure on parking lots.

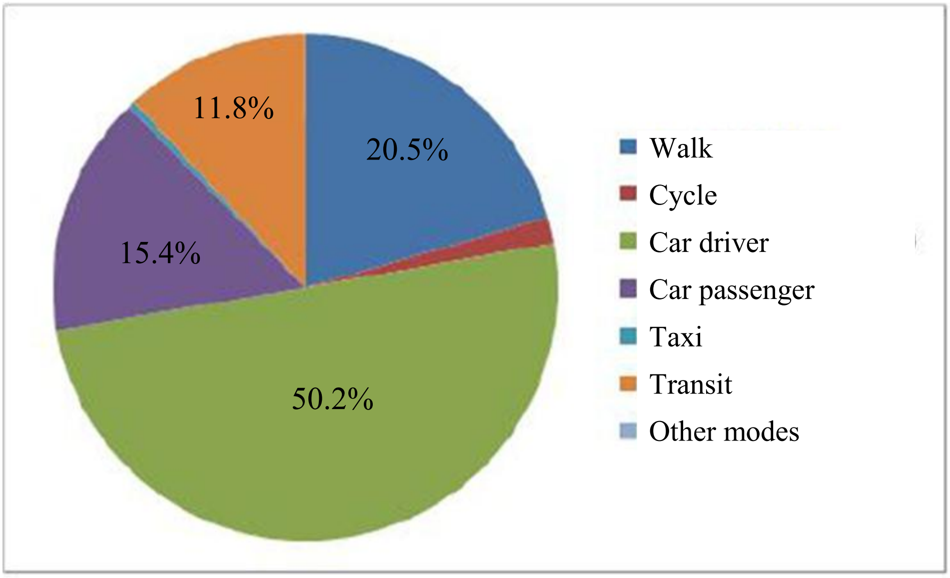

Figure 5. Modal split of access to rail stations

This analysis was conducted for each station and focused on the three main access modes: walking, car (driver + passenger) and transit. A k-mean algorithm is applied to create classes of stations with similar modal share for access modes. Four types of stations are outputted from the method. The mean shares of the main modes are presented in Table 2 for the four types:

- **Type 1**: Stations where users prefer the car to all other modes for access movements. Modal share of walk is much lower that in other types.
- **Type 2**: Stations with an important share of walking as access mode and a lower share for car.
- **Type 3:** Only two stations fit into this group: it is characterise by very high access by foot (more than two thirds) and the lowest proportion of access by car. The low access by car is clearly related to the fact that there is no official parking available at these two stations.
- **Type 4:** These stations have the highest share of access by transit with a share of 22%. It is still low when compared with the levels other modes can reach in some stations.

Table 2. Typical modal share (main modes) for the four types of stations

	Type 1	**Type 2**	**Type 3**	**Type 4**
Number of stations	14	15	2	10
Walk	12.8%	34.8%	67.2%	13.5%
Car	76.9%	58.0%	27.1%	62.1%
Transit	9.0%	3.8%	4.2%	22.4%

Access distances to stations

In addition to access mode, access distance is another relevant feature of the decision to use suburban rail or not. Figure 6 presents the cumulative distribution (in percentage) of users according to access distance. We see that the distances are relatively small with half the users within less than 500 meters (straight line distances). More than 90% of users are within a 1 kilometer ray from the station. Such distribution can however vary depending on line, station, traveller's attributes, etc. To easily compare distributions, we use the concept of threshold distance. We define threshold distance as the distance that 80% of the people belonging to a specific group accept to travel. It is estimated by mode and is presented for each rail line and population segment. This concept will be used in some analysis to circumscribe typical access areas and estimate the potential of various modes namely walking.

- Figure 7 presents threshold distances by mode and rail line. As expected, the smaller distances are observed for walking and there is not much variability between lines. Car driver threshold distances are the largest for every line but are also higher for the DM line with almost 8 km. With respect to walking, a study by El-Geneidy et al. (2010) also conducted for the Montreal region reveals that the 85th percentile walking distance to bus transit service is around 550 meters from the origin. In comparison, rail stations have wider walking cachment area, approaching 1 km.
- Figure 8 presents threshold distances by mode and population segments. Again, walking as the smallest distances and this one is decreasing with age. We see that the 65 years and older have the largest threshold distance by transit.

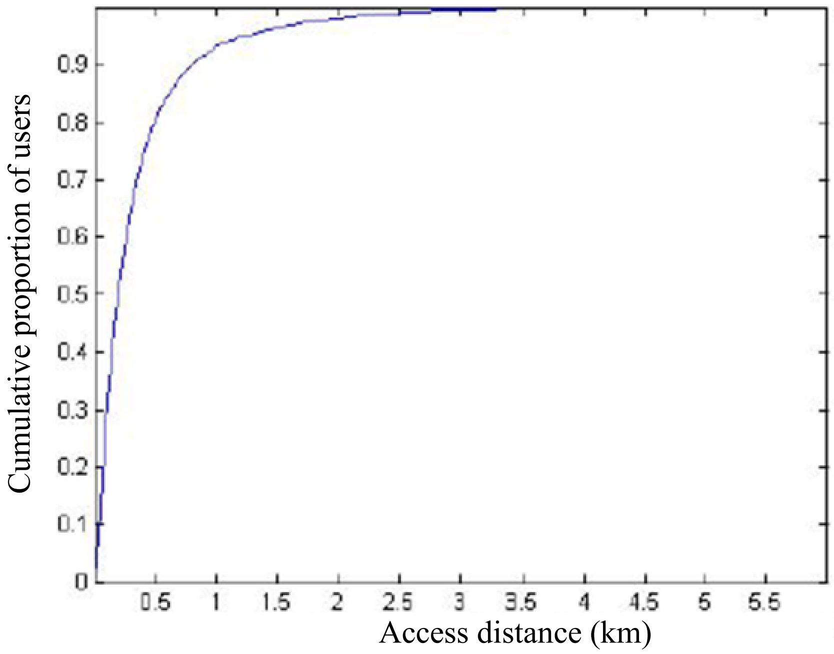

Figure 6. Cumulative distribution of access distance to rail stations

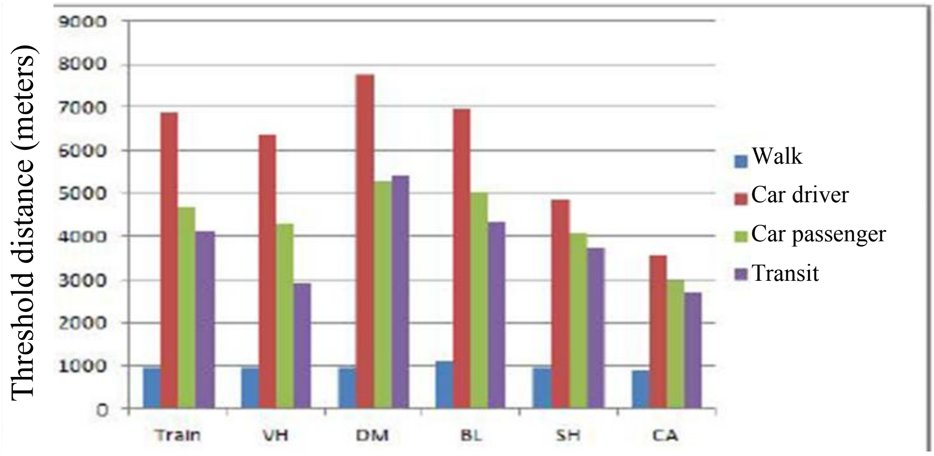

Figure 7. Threshold distances for the main access mode, by rail line

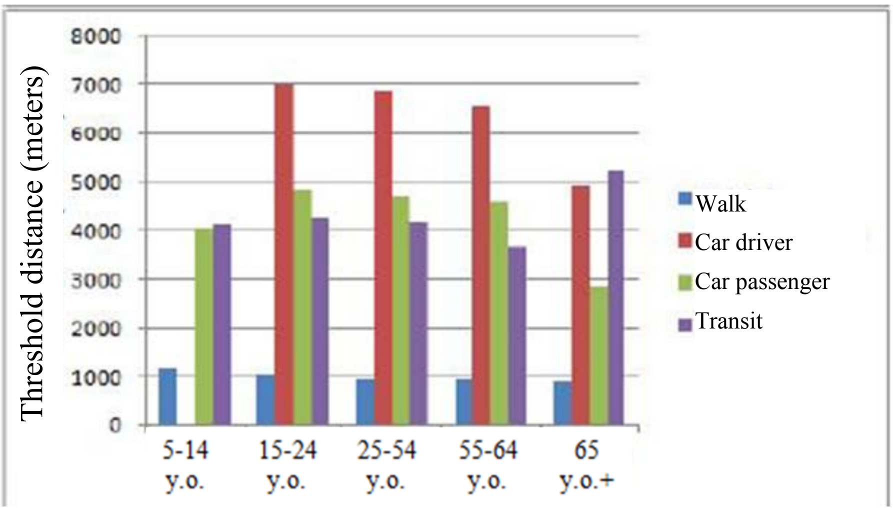

Figure 8. Threshold distances for the main access mode, by population segment

CATCHMENT AREAS OF RAIL STATIONS

The next step of our analysis is to define attractivity zones or catchment areas of rail stations.

Delimitation of zones based on users' origin points

Our first definition relies on origin points of users that board at each station. We make use of the threshold distance concept, previously defined, to circumscribe the attraction area of each station. This simple application allows observing differences among stations by showing what distance users are willing to travel to access the rail network using a particular station.

There are various ways to translate the threshold distance into attraction zones:

- **Uniform attraction around the station**. Using the threshold distance, the first 2D adaptation is to suppose that attraction is uniform around the station. The resulting surface is hence a circle which ray equals the threshold access distance.

- **Convex Hull**. The section approach is to circumscribe the attraction zone by a convex hull around the 80% nearest origin points of station's users.
- **Refined attraction zones**. In order to provide a more relevant delimitation of attraction zones, a refined approach is proposed. It relies on the origin-station desire lines (straight line between origin point and station) of the same 80% nearest users instead of only origin points. Space is discretized into cells and counts of desire lines are estimated to output density of desire lines. The resulting attraction area includes all cells with at least on desire line. This technique was applied using cells of 250m *250m. Since densities of desire lines are also outputted, it is possible to identify cells with same level of theoretical exposition to users (iso-exposure cells).

Figure 9 presents the attractivity zones resulting from the three described approaches. The spatially uniform hypothesis can rapidly be put aside, especially in cases as illustrated in the figure where there is a physical barrier such as a river. Convex Hull addresses some of the limitations of the circle by being more fitted to the observed demand but still includes areas where there is no demand. The use of desire lines helps identify main directions from which users are coming from and definitely circumscribes attractivity area in a more pragmatic way.

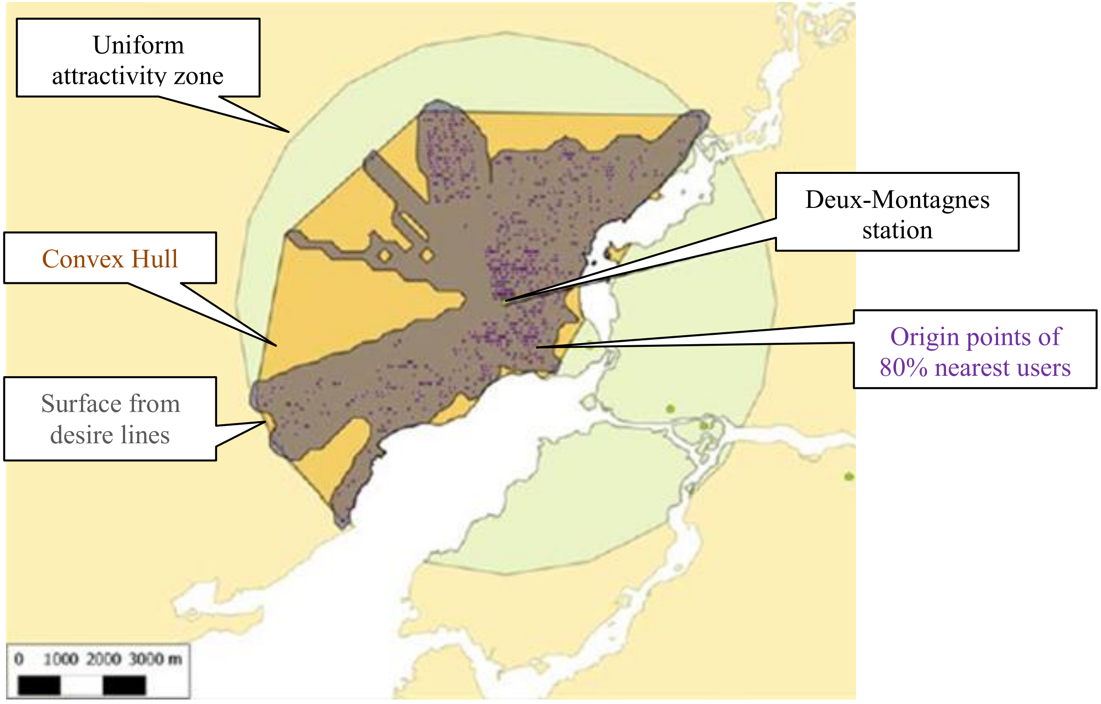

Figure 9. Comparison between definitions of attraction zones

Typology of stations based on attractivity zones

The attractivity zone of each station is estimated using the desire line approach and results show that scale of zones is highly variable. Using a k-means algorithm, stations are clustered into three groups based on the scale of their attractivity zones. This allows identifying regional (with widest attractivity zones), intermediate and local stations (smallest attractivity zones). There are two regional stations, one located in a suburban area, at the end-point of a line and the other one near the central part of the Montreal Island. The two regional stations have quite different surroundings, one being at the end of a line and quite isolated from other stations (nearest station from the same line at around 10 km) and the other one (shown on the previous map) in the middle of an urbanised area with multiple stations within 5 km. This second regional station clearly offers attributes that make it more attractive to users than nearest stations. High parking capacity is certainly an explanation, along with proximity to one main highway. Local and intermediate stations and diffused over the lines. Figure 10 presents attractivity zones for the three types of stations (regional, intermediate and local). Differences are easy to observe.

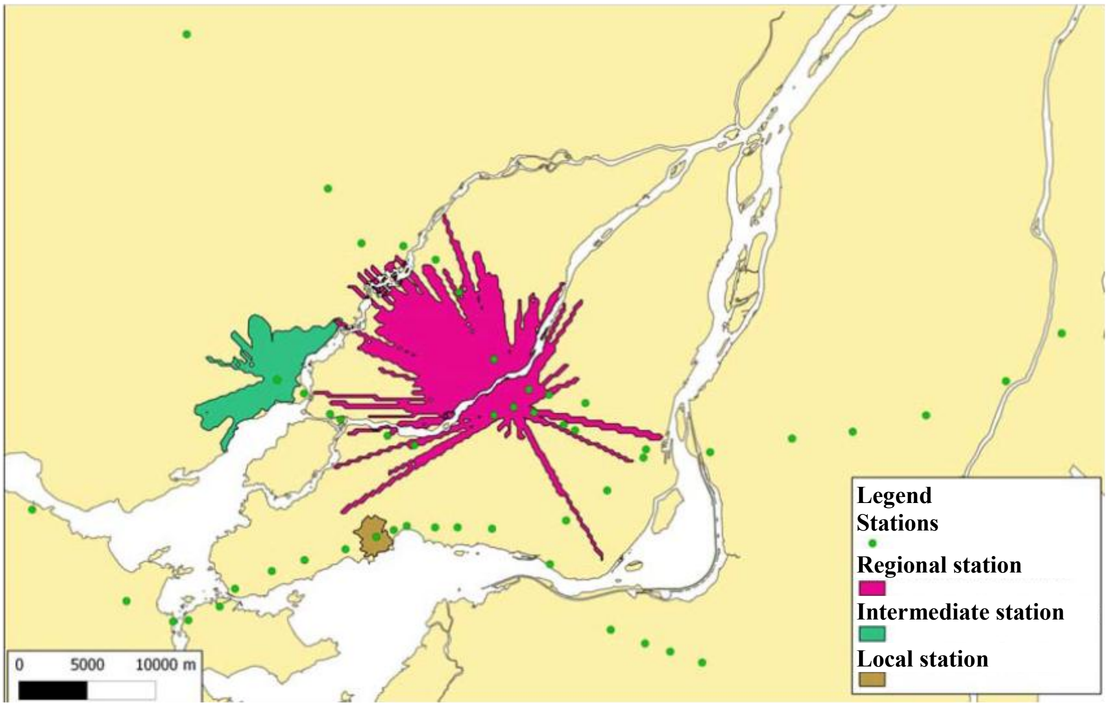

Figure 10. Attractivity zones for three stations: one local, one intermediate and one regional

IMPACTS OF DENSITY INCREASE ON RAIL USAGE

As a first attempt to estimate the impacts of the minimum density criteria's in the surroundings of stations, we combined forecasted new dwellings capacity in the surroundings of stations and current market share supposing that these would remain constant over time. Hence, new dwellings in the attractivity zones of stations translate into new suburban rail users. Current market share is estimated using GIS functions that combine home location of users and population estimates from the censuses.

The impact of population density increases in the surroundings of stations varies by line and stations. For well established lines (those that have been operating for more than 20 years), the increase is much smaller than for newer lines. The rate of increase by line varies from 5% to 70%. Variability is even higher when impacts are looked at from a station perspective. Some stations located on the Montreal Island are already settled in high density areas while other, further from CBD, are near highways interchange with no dwellings within walking distance. The benefits of increased density will be much more spectacular for rail use in these areas. In addition to bringing more people to the station, it will facilitate access using active modes such as walking or cycling. Hence, it must be mentioned that saturation of the run will become an issue if such demand actually results from increased density and that additional departures will be required.

POTENTIAL OF WALKING FOR STATION ACCESS

According to Moudon et al. (1997), residential density has a positive impact on walking i.e. that walking is generally higher in areas with high density than in those with low density.

The last element that is looked at is the potential of walking to access the station. To feed this estimation, walk attractivity zones are constructed using the desire line density approach but using only the origin points of those accessing the station by foot. Again, the 80% threshold is used. Figure 11 shows the attractivity walk zone for one station as derived using the desire line density approach limited to origin points from which access to the station is by foot.

The same figure also shows the users that are within the walking zone but that use another access mode. These represent potential walkers. This technique, inspired by the work of Morency et al. (2007), is used to estimate the potential of walking to access rail stations across the network but with additional elements. If all users located in the walk zone of a rail stations were to walk, then the proportion of walking as an access mode would reach 29.4%, compared with 20.4%. It would alleviate parking capacity issues at some stations as well as promote healthier ways to travel.

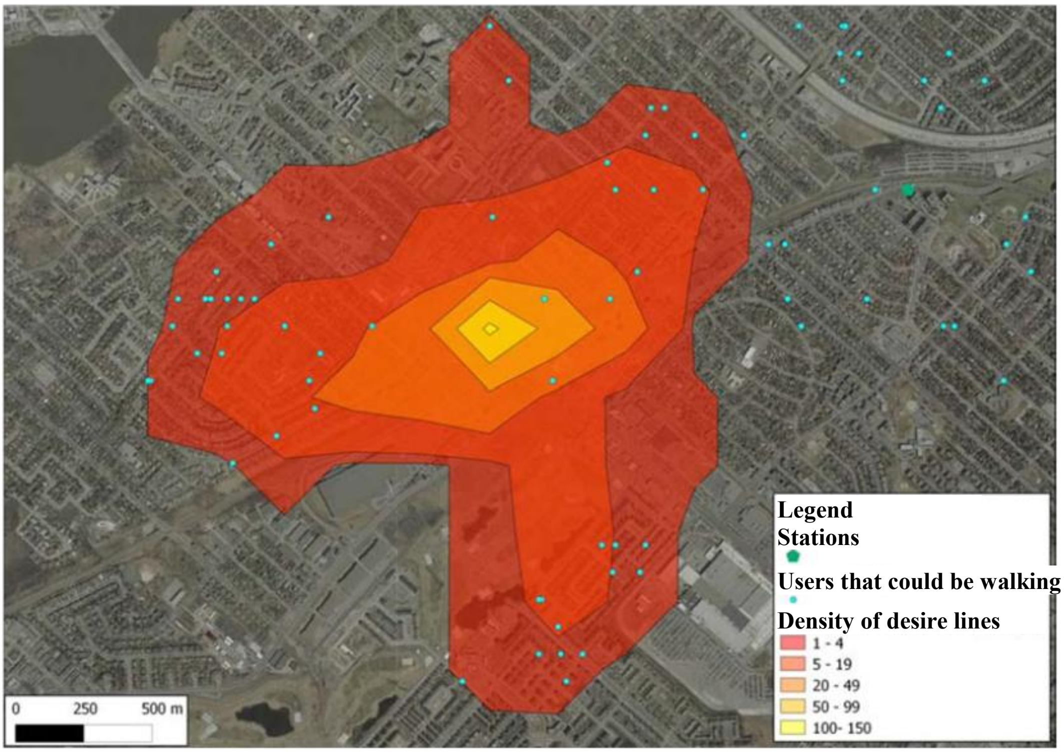

Figure 11. Illustration of an attractivity walk zone using the desire line density approach for access by walk

CONCLUSION

This paper has presented some descriptive analysis of the rail usage in the Montreal Area. The topic is of particular interest since land-use strategies were recently adopted, namely density targets in the surroundings of rail stations. In addition to providing key elements of access to station modal split, this paper proposed a method to circumscribe catchment areas using the concept of desire line densities. The outputted surface is much more relevant and fitted to physical barriers and real demand than simpler buffer of fixed distance around stations. This paper has also provided estimates of the potential of walking to access rail stations as well as insights into the impacts of forecasted dwelling construction near stations.

Results from this study are particularly relevant in the current Montreal context where a new metropolitan urban plan has just been approved and sets densification targets around rail stations. This research generates market intelligence that planners can use as tools for decision support in planning projects.

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