Understanding the relationships between regional accessibility travel behaviour and home values

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July 2009

Paper submitted for presentation at the Transportation Research Board 89th Annual meeting 2010

ABSTRACT

Accessibility is a comprehensive measure of the interaction between land use and transportation systems. It has been put forward as a performance-measure for evaluating the land use and transportation performance, transportation plans and projects. However understanding the effects of accessibility on household choices such as travel activity and home location and values has been less studied. In this research paper, we study the effect of regional accessibility on individual travel behaviour, as well as its monetary value in residential property markets. First, accessibility to jobs and workers by automobile is generated for the entire region. Second, the actual activity space of each household in the sample is generated. Using a linear regression, the spatial dispersal and area of the household activity space, as well as the total distance traveled are predicted using the inverse balancing factors of the doubly constrained spatial interaction model of regional accessibility, while controlling for household and neighbourhood characteristics. In addition, residents' willingness to pay for higher levels of accessibility is measured through a hedonic regression. The models show that households with high levels of regional accessibility to jobs have smaller, less spatially dispersed activity spaces as well as shorter travel distances than those with lower levels of regional accessibility, while controlling for household and neighbourhood variables. In a second model, we found that accessibility has a positive effect on home sale values. This study underscores the importance of using accessibility and activity spaces as performance-measures for land use and transportation planning. It shows the effects of regional accessibility on household choices. These measures will help transportation planners gain insight into travel behaviour, travel demand and help to plan for more sustainable outcomes.

Keywords: Accessibility, Mobility, Land use and Transportation planning, Household Accessibility.

INTRODUCTION

Cities are becoming increasingly congested making sustainable mobility a pressing issue. Rather than emphasize increased speeds and capacity of roads, transportation planners are now looking for solutions to bring opportunities closer to people and reduce the need to travel. Measures of accessibility are gaining popularity as comprehensive performance measures of the interaction between land use and transportation systems. Planning for accessibility has more sustainable outcomes than planning for mobility alone [1].

Accessibility has been put forward as a performance measure for transportation planning. By favouring shorter distances and active modes of transportation, and influencing household location choices, accessibility can also be used as a sustainability indicator and a land-use planning tool. While the literature on the subject is abundant, the measures are seldom used in practice. One reason for this may be the lack of understanding of the relationship between regional accessibility and individual choices. Individual willingness to pay for increased accessibility has been estimated in a couple of studies [2, 3] using simple measures of accessibility, but the observed effect of high accessibility levels on household behaviour has seldom been explored.

This research paper explores the relationship between regional accessibility levels, housing prices and travel activity patterns. It uses various measures of accessibility and new space-time representations of household travel behaviour to analyse the influence of opportunities on compact and spatially dispersed travel patterns. This research attempts to quantify the influence of several measures of regional accessibility (cumulative opportunity, gravity, and competitive) on household travel and home values. Several measures of travel behaviour are tested (activity area, compactness and travel distance), and a new measure of travel behaviour, that of spatial dispersal, is presented. After controlling for socioeconomic factors and neighbourhood characteristics, the models explore the degree of association between several dimensions of accessibility and household behaviour.

This paper commences with a discussion of the measures of accessibility and the space-time framework. The next section pertains to the methodology used to prepare and analyze the data for developing regional accessibility measures and household activity spaces. The results of the models are then summarized, followed by a discussion of the results and a conclusion with policy recommendations for city and regional planners.

ACCESSIBILITY AND SPACE-TIME GEOGRAPHY

Definitions

Accessibility is defined as the potential of opportunities for interaction [4] and is often contrasted with mobility [5]. Accessibility considers the interaction between the land-use and transportation systems. Rather than measure the ease of travelling along a network, accessibility measures the ease of reaching destinations. Accessibility was first modeled in the late fifties [4], and many researchers have further developed the concept since. A number of review studies classify and evaluate the measures according to various criteria [2, 6-8].

Components
All accessibility measures are built with a transportation component and an activity component [2, 9]. The activity component is a measure of the land use system, represented by opportunities. The transportation component consists in a measure of the transportation system, such as travel time or distance. A measure of the cost of travel (the impedance) to the users is also included in the transportation component.

Regional Accessibility
Accessibility can be measured for a place, involving measurements of spatial separation of individuals and certain activities, or for individuals or households [10]. It is important to clearly set out the goal before selecting which measure to use and select the most appropriate description of access [11], taking into account the type of activity and destination in the definition of distance.

There are several measures of accessibility in place. In this research paper we will concentrate on three measures and compare their effect on household actual activity spaces, used in this research as a proxy for individual accessibility. The first two measures, the cumulative opportunity and gravity models, are well known and frequently used. The third measure, the inverse balancing factors of the doubly constrained spatial interaction model [12], will be described in depth.

Cumulative Opportunity and Gravity Models
The cumulative opportunity measure counts the number of opportunities available from a predetermined point within a certain travel time or travel distance. It is defined as

$$A_{im} = \sum_{j=1}^{J} B_j O_j$$

Where A_i is the accessibility measured at point i to potential activities in zone j, O_j is the opportunities in zone j and B_j is a binary value equal to 1 if zone j is within the predetermined threshold and 0 otherwise.

Cumulative opportunity has often been used in the literature as a simple, straightforward manner of evaluating equity in accessibility to public goods or changes in accessibility brought about by transportation infrastructure [11, 13, 14]. However, it does not account for the size of the facility or the impedance of reaching it, so all opportunities are considered equal. The gravity model compensates for this by introducing a travel impedance function that will weigh opportunities according to their distance from the point of origin. This creates a balance between the utility of a destination and its required travel cost [10].

$$A_{im} = \sum_{j} O_j f\left(C_{ijm}\right)$$

Where A_{im} is accessibility at point i to potential activity at point j using mode m, O_j is the opportunities at point j and $f(C_{ijm})$ the impedance or cost function to travel between i and j using mode m.

The cumulative opportunity and gravity model are simple to calculate, use readily available data and are easy to understand and communicate by planners. However, they measure the accessibility of a location and do not account for individual accessibility. All individuals within a zone are attributed the same level of accessibility, despite any real or perceived constraints that might actually lower their accessibility[15].

Within a given zone individuals may have different levels of accessibility due to personal constraints. A location may have a high accessibility to jobs, but an individual without the qualifications for the type of jobs available may still have a low level of accessibility to employment. If competition has an impact on the activity that is measured, for example because the spatial distribution of the demand is uneven, an accessibility measure that does not account for competition effects will be false or misleading [16, 17].

Accounting for Competition

Several equations have been developed to account for competition factors. A first approach has been to measure accessibility to certain opportunities (jobs) and to individuals (workers) from a given location and then divide one measure by the other [18]. This only accounts for competition effects at one location and doesn't apply to employment, competition for a job can originate from anywhere in a region [16].

A second approach, applied by Shen [17] involves incorporating the demand potential (job seekers) to the calculation by dividing the supply (jobs) located in destination zone j by the demand potential within reach of that zone *j*. In this model, accessibility is equal to the ratio of the total number of opportunities to the total number of opportunity seekers in zone *j*. This model may overestimate competition because it accounts for the number of potential job seekers, but not for the impact of other jobs in other zones [16]. The third approach, and the one used in this research paper, is using the inverse balancing factors of the doubly constrained spatial interaction model as an accessibility measure [12]. In Wilson's interaction model the balancing factors ensure that the magnitude of flow originating from and destined for each zone equals the actual number of activities in the zone.

With this measure the supply and demand potential for all the zones is calculated iteratively, ensuring that the amount of trips to and from each zone is equal to the number of opportunities [16]. In other words, it calculates all the potential opportunity-seekers (E_i) for the area as well as all the potential opportunities available (O_j) and balances the numbers until the model is stable. Using accessibility to jobs and number of potential job seekers, this model can be explained as:

$$A_{im} = \sum_{j=1}^{n} \frac{1}{B_j} O_j f(C_{ijm}), \quad (1) \qquad B_{jm} = \sum_{i=1}^{m} \frac{1}{A_i} E_i f(C_{ijm}) \quad (2)$$

A_{im} is the accessibility to jobs for people living in location *i*, using mode *m.* While, B_{jm} accessibility to workers at zone *j* using mode *m*. O_j is the number of opportunities (jobs) in zone *j*, E_i the number of opportunity-seekers (people) in location *i*, and $f(C_{ijm})$ the impedance function measuring the spatial separation between *i* and *j* using mode *m*.

The first step to operationalizing the measure is to calculate the accessibility to jobs for all zones, making the balancing factor B_{jm} equal to 1 (1). This amounts to calculating a gravity measure for all zones. The result of this A_{im} is incorporated to the calculation of the second factor B_{jm} (2). That result is then incorporated back into to the first factor A_{im} (1) and so on until a balance is reached. The model has converged when the results of two consecutive A_{im} factors are identical. In order to map the results or apply them as variables in a linear regression, it is better to scale them by multiplying the A_{im} factor and dividing the B_{jm} factor by a constant.

Households and Accessibility

Regional accessibility measures are location-based measures. They measure the accessibility of an area and cannot accurately represent the accessibility levels of individuals. Ideally, disaggregated measures should be produced, such as including job matching factors to the measure of competition. Even this however cannot account for individual choices and constraints. Individual accessibility measures based on space-time geography [19] have been proposed in the literature [10, 20]. Individual accessibility measures are recognized to be data intensive and difficult to operationalize. In order to link accessibility to individual choices and actions, while still maintaining the relative simplicity of the location-based approach, the concept of activity spaces – also taken from space-time geography – can be used to describe household travel behaviour and work as the base for individual accessibility, when time spent at destinations is known.

Understand the monetary costs associated with accessibility is a recognized and valid approach [7, 21], yet previous studies used simple measures of accessibility in doing so. Accessibility is expected to have a positive impact on home sale.

Space-time Framework

The space-time framework was first proposed by Hagerstrand [19]. It accounts for the spatial and temporal dimensions of participating in a given activity. Activities take place at a given location at a given time, for a specific duration [22]. The transportation system determines travel speeds and network constraints which affect the amount of time available to participate in activities at dispersed locations [23]. The space-time prism is the area within which a person can move during the day considering the amount of time that must be spent on various activities at different locations, and the time constraints they face. In order to participate in all mandatory or desired activities during one day, a person can only travel so far, therefore maximum travel times and distances determine the area of the time-space prism.

Mapping the space-time prism onto a two-dimensional geographic space creates the potential activity space, which is the area containing all the activities an individual can participate in or all the locations an individual can be at, given their space-time constraints [20, 22]. The potential activity space can be used as an individual accessibility measure [24-26]. Another application of the space-time prism is to map actual (rather than potential) activity spaces using observed or reported travel behaviour. Several studies have used data acquired through travel diary surveys to analyse the spatial representation of individual travel behaviour [27, 28]. The actual activity space does not represent, as with the potential activity space, an individual's maximum area within which to travel and participate in activities. Instead the actual activity space is representative of reported travel behaviour and is equal to an individual's typical area within which he travel on a given day [28].

The actual activity space has been used in the literature as a measure of travel behaviour to better understand travel demand [28], or more specifically the difference between single-worker household and dual-worker household travel patterns [27, 29], and as an indicator of social exclusion [30].

In this research paper, we use the actual activity space as a proxy for individual accessibility. The actual activity space is expected to be affected by the levels of regional accessibility measured at the home location. The characteristics of actual activity space can be measured in various ways. It can be measured through total distance traveled by a household, area of activity space, compactness of activity space, and a new measure that we propose in here which is the spatial dispersal of the activity space. It is important to note that these measure are not used to account for the potential for interaction by individuals, but for the accessibility the household actually benefits from.

Actual Activity Spaces

Previous studies used the absolute area of the activity space and the total distance traveled to estimate how these are affected by urban form and neighbourhood characteristics [28, 31]. These measures can be deficient to explain compact, local travel behaviour. The total distance traveled by a household does not account for the direction of travel or the resulting use of space. The area of the polygon can also be misleading. When comparing polygons, it becomes apparent that having a small area does not necessarily mean having local travel behaviour. Figure 1 shows a comparison of polygons according to the generated measures. Polygons A-1 and A-2 have the same area but correspond to very different travel behaviours, A-1 has more trips close to the origin point, while A-2 has a very long trip, but only in one direction. A measure of compactness is used to separate these two travel behaviours [32]. Compactness is a ratio between the area of the polygon and the area of the circle that can include this polygon. Other measure of compactness is looking at the ration between the area of the polygon and the area of a circle that has the same perimeter.

The measure of compactness is defined as

$$Comp = \frac{A_r}{p^2}$$

Where *Comp* is the compactness of the polygon, A_r is the area of the polygon and P is the perimeter of the polygon. This measure defines a circle around the polygon, and creates a ratio between the area of the circle and the area of the activity space. This separates household's having similar areas with long travel distances from those with short ones, but as shown by polygons B-1 and B-2, this measure does not differentiate between a household with very local activity patterns and ones with more distant ones.

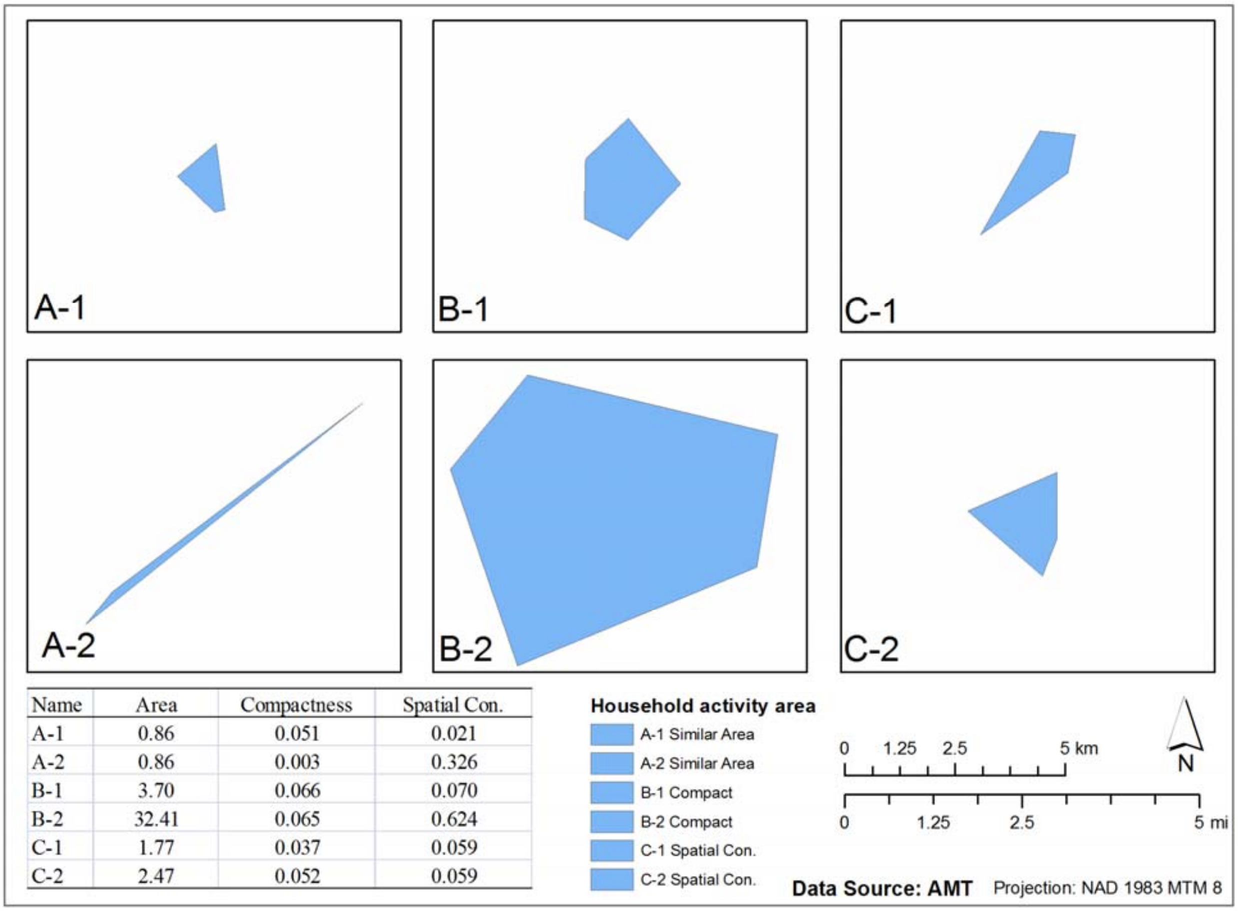

Figure 1: Comparisons between different measures of household activity

In order to obtain a reliable measure of individual travel activity the measure of compactness is modified to account for spatial dispersal. The measure of spatial dispersal relies mainly on area ratios and compactness, creating a bridge between the above-mentioned measures. The spatial dispersal of the activity space can be defined as:

$$\text{Spatial dispersal } = \frac{A_r}{A_{max}} * \frac{A_r}{p^2}$$

Where A_r is the area of the activity space of a household, $A_{max,}$ is the area of the largest polygon in the sample, and $\frac{A_r}{p^2}$ is the compactness of the polygon measured earlier. As seen in Figure 2, polygons C-1 and C-2 have the same level of spatial dispersal as well as a similar area and compactness. A person with a low value of spatial dispersal is expected to live in an area with high levels of regional accessibility, while controlling for other socio-demographic and neighbourhood characteristics. The spatial distribution of this measure at the regional scale could be used for social equity analysis. Accordingly, this measure can have several applications in the planning field. In this research paper we examine how it is influenced by regional accessibility levels and how this new measure can be used as a proxy of travel behaviour patterns.

The Value of Accessibility

The location of the house in relation to certain amenities, or to the transportation system plays an important role in the home buyer's decision making process. Accessibility has long been considered an important factor in housing location and land prices [33]. In a residential property market part of the amount paid to purchase a home is directed towards accessibility to valued destinations. The value of access is capitalized into the home value and purchasers' willingness to pay can be interpreted as the accessibility of a location [34]. Simply put, accessibility for a location can be measured through its value as an attribute in the housing package.

Hedonic regressions are used to evaluate the importance of accessibility in the home purchase decision. Distance variables are usually used as a proxy for accessibility, such as distance to the CBD or to neighbourhood amenities. Accessibility to jobs was proven to have a positive impact on land values in three separate studies [7, 21, 34]. A recent study that used an accessibility index accounting for competition factors [33] found accessibility has an important effect on home prices in central neighbourhoods, but a much lower effect in suburban areas. This introduces the need of more refined measure of accessibility to be included in these models.

DATA SOURCES

Accessibility to jobs, workers is calculated for the study area using the three accessibility measures. These measures are generated at the transportation analysis zone (TAZ) level of analysis. The TAZ used in this study are obtained from the Québec Ministère des transports (MTQ). The MTQ also provided the research team with a congested automobile travel time matrix that is generated with travel demand modeling software. Employment and demographic information is obtained from the 2006 Census undertaken by Statistics Canada. Cumulative opportunity measure of accessibility are generated for retail (food stores). Retail and business information is obtained from the Dun and Bradstreet commercial database using the North American Industry Classification Code (NAICS).

In order to generate an accurate gravity measure of accessibility a travel time decay curve was calculated by combining travel times obtained from MTQ with travel behaviour data obtained from the 2003 Origin-Destination survey conducted by the Agence métropolitaine de transports (AMT) [35]. This decay curve is used to generate the gravity measure of accessibility, as well as the inverse balancing factors. The OD survey is conducted every 5 years and records the trips of every household member for one day. The OD data is aggregated to the household level to study household travel patterns. A sample of 22,930 households with at least three reported trips was used to generate the actual activity spaces. First household trips are mapped using the origin and destination X,Y coordinates in a GIS environment. Then the Convex Hull application in GIS is used to generate the smallest polygon possible for each household. This polygon corresponds to the household's actual activity space.

In addition, data obtained from the Montréal multiple listing services (MLS) is used to generate a hedonic model. A sample of 1961 transactions that occurred in2006 was used. The MLS data includes detailed information regarding building characteristics. In addition, neighbourhood characteristics for each house are calculated from various sources. For example the land use is obtained from the CanMap dataset and the street center line files are obtained from DMTI street files.

ANALYSIS AND DISCUSSION

Regional accessibility measures

Although this measure produces convincingly more accurate results, the iterative process incorporating both the locations of supply and demand makes it more difficult to interpret. One advantage of this measure is that it does not overestimate the impact of the center. The cumulative opportunity and gravity measures invariably produce a monocentric representation of accessibility to jobs that gradually fades towards the edges. See Figure 2 and Figure 3 for the comparison between the cumulative opportunity and inverse balancing factors measures of accessibility. Figure 3 is generated using a congested travel time decay curve generated from a travel behaviour survey [35]. In Figure 3, the importance of the central island fades to reveal a more complex pattern of accessibility. Areas with higher values have access to more job opportunities after controlling for the number of people competing for these jobs.

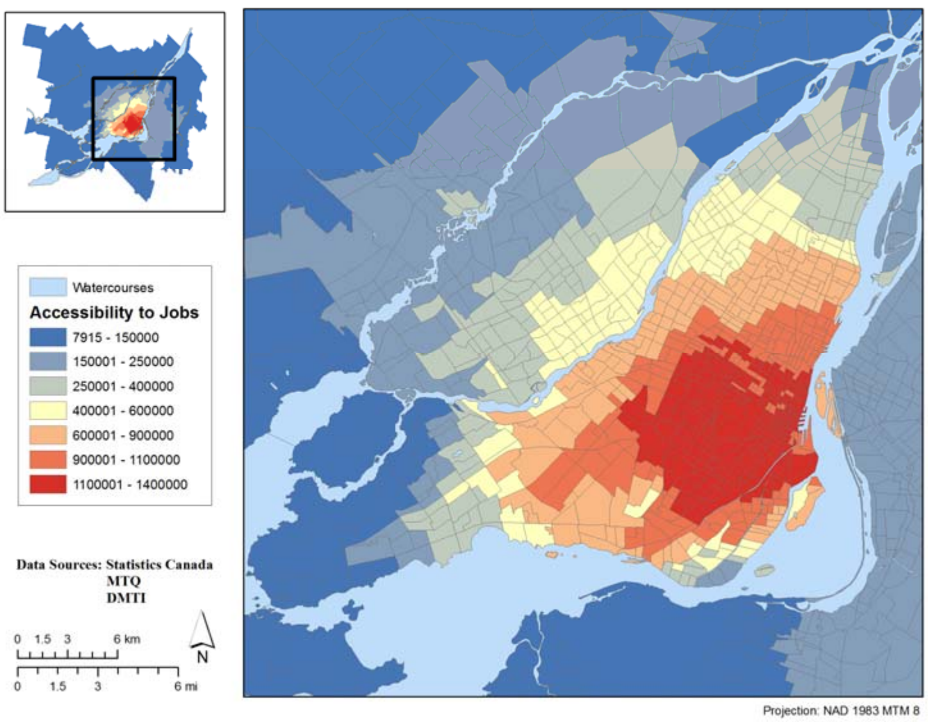

Figure 2: Accessibility to jobs using cumulative opportunity measure (number of jobs within 30 minutes of travel time with car)

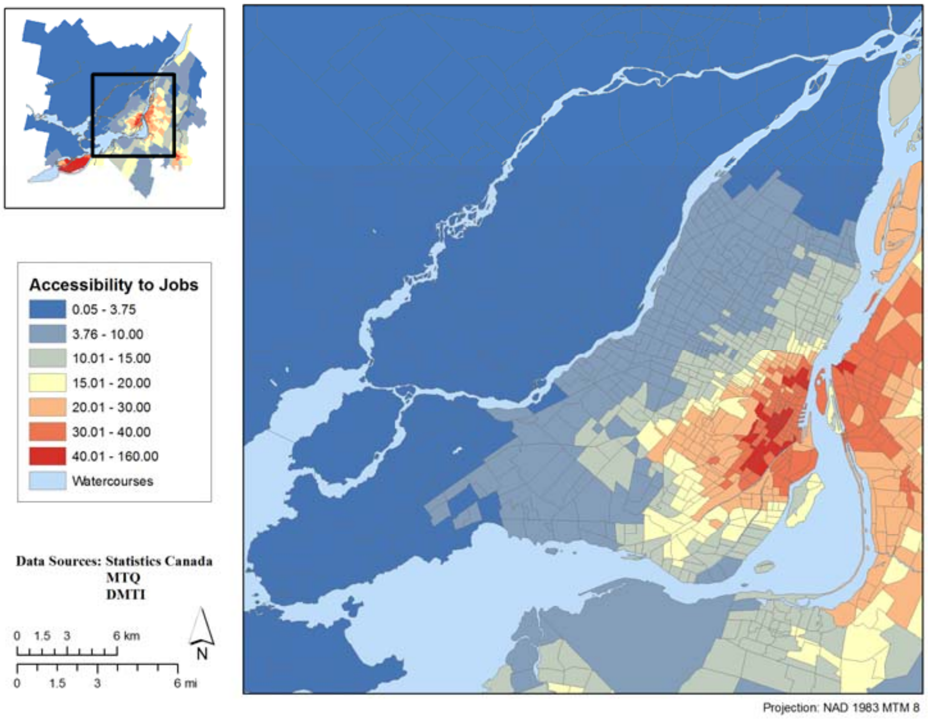

Figure 3: Accessibility to jobs using the inverse balancing factors of the doubly constrained spatial interaction model

Activity space

In order to explore the relationship between the different measures of the activity space and the land use and transportation system, a clusters and outliers analysis is con-ducted using GIS to identify where low or high values cluster spatially. High values surrounded by concentrations of low values, and low values surrounded by high concentrations of high values are also indentified. As a first step in this analysis the data was transformed to represent location-based characteristic rather than individual travel behaviour. The spatial dispersal values for the 22,930 households were aggregated to the TAZ level. Each TAZ is given the average value of each of the spatial dispersal variable. The resulting clusters do not represent individual spatial patterns, which vary greatly according to personal characteristics, but average travel behaviour at the TAZ level, which account for the particular opportunities and constraints people living in that TAZ may encounter.

Figure 4 shows the clustering patterns of the spatial dispersal factor. High values are located on the eastern and western parts of the island of Montreal, as well as Laval and the immediate North Shore, while low values are clustered in the central island, extending slightly more towards the east and in parts of the South shore.

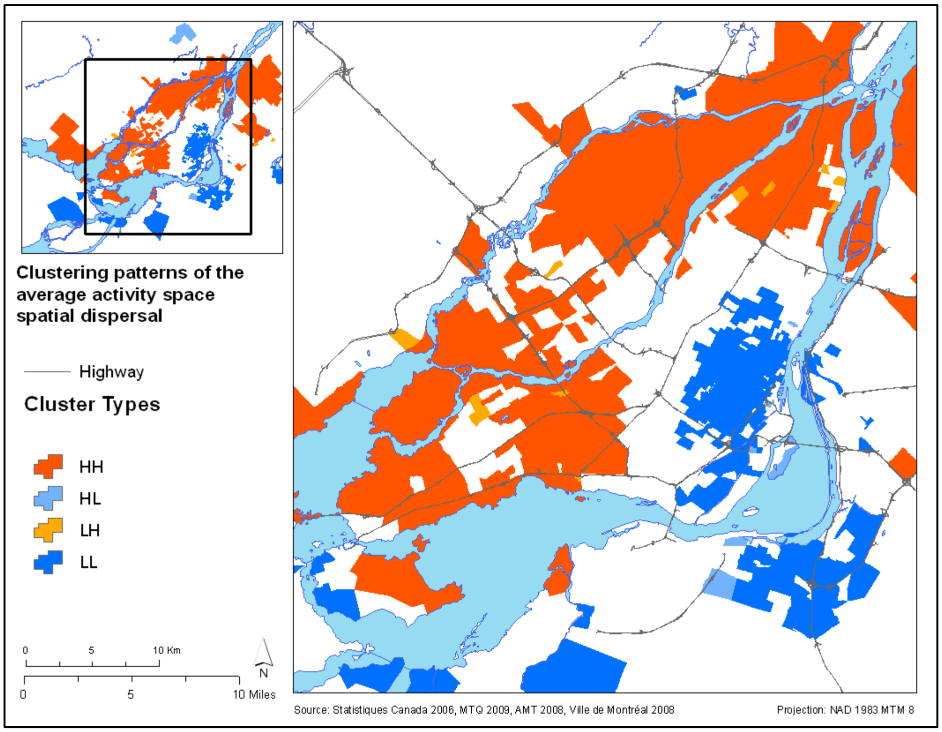

Figure 4: Clusters of high and low values of spatial dispersal

Visually comparing the clustering of areas with low spatial dispersal values in Figure 4 with the competition measure of accessibility in Figure 3 can reveals a clear correlation between the two measures. Yet this correlation needs to be validated statistically. The above maps are mainly used as part of an exploratory analysis of the data.

Statistical analysis

The first set of statistical models explores the relationship between small, localised activity spaces and accessibility to jobs, workers and retail. The dependent variables are the natural log (ln) of the activity space's spatial dispersal, area, and the total distance traveled (km). Table 1 includes a list and description of the variables used in the analysis as well as summary statistics.

Table 1: Variable name and summary statistics

Variable	Description	Mean	STD.
Ln(Sp. Conc.)	Natural log of activity space spatial dispersal	-0.60	1.76
Ln(Area)	Natural log of area covered activity space	15.89	2.07
Total Distance	Total distances traveled by household residents	46413.02	40153.22
Vehicles	The number of vehicles owned by the household	1.31	0.88
Num People	The number of people in the household	2.44	1.15
Avg. Age	The average age of the household inhabitants	38.49	14.79
Income less 60K	A dummy variable if the household income is less than 60K	0.62	0.48
Num. Driver lic.	The number of people with a driver licence in the household	1.66	0.82
Total Trips	The total number of trips made that day in the household	7.24	3.91
Num. Active Trips	The total number of trips using active modes of transportation made that day in the household	0.94	1.96
On Island	A dummy if the household is located on the island of Montréal	0.64	0.48
Dist Job Center	Network distance from the home to the nearest job center	4157.82	3824.08
Num Retail	Number of retail opportunities in a 1km buffer around the home	592.90	812.80
Food Sto. 10min	Number of food stores within 10 minutes of travel time by car	180.50	127.49
Num jobs 30 min	Number of jobs within 30 minutes travel time by car	728900.39	417179.56
Num workers 30 min	Number of workers within 30 minutes travel time by car	700730.48	316293.82
Gravity jobs	Gravity based measure of accessibility to jobs	43090.32	24660.50
Gravity workers	Gravity based measure of accessibility to workers	41332.72	17648.54
Competition jobs	Balancing factor for accessibility to jobs	14.93	11.83

Spatial Dispersal of the Activity Space

Although the area and the total travel distances have higher R squares compared to the spatial dispersal model, the spatial dispersal factor offers a new measure that accounts for the direction, compactness and scale of the activity space. Similarities exist in terms of the behaviour of the independent variables and their effect on the spatial dispersal and the area of an activity space. The main differences are in the power associated to the independent variable by each of the dependent variables.

The spatial dispersal of an activity space is expected to increase by 29% for every additional vehicle in the household. In addition, it is expected to increase by 6% for every additional person residing in the household. These two variables follow the expected theory that more people in a household will lead to an increased area and more dispersed travel patterns. An annual household income of less than $60,000 decreases the spatial dispersal factor by around 44% compared to households earning more than $60,000. Accordingly, the level of income is reflected in the spatial dispersal factor as well as in the activity space area. The total number of trips generated by a household is expected to increase the spatial dispersal factor 4%, while the total number of trips made using an active transportation mode decreases it by 20%. Montréal has 6 job centers defined by Coffey and Shearmur [36]. The spatial dispersal factor is expected to increase by 5% for every kilometre separating the home from the nearest job center.

Table 2: Statistical models measuring the relationship between personal and regional accessibility

	Spatial dispersal						Area		Total distance	
	Cumulative opportunity		Gravity		Balancing factors					
	B	t	B	t	B	T	B	t	B	t
Num. Vehicles	0.290327*	15.82	0.30090*	16.34	0.279666*	15.31	0.296421*	13.92	5587.2220*	14.14
Num. People	0.064325*	3.77	0.07060*	4.11	0.061199*	3.59	0.063404*	3.19	2309.5596*	6.27
Avg Age	-0.018686*	-21.41	-0.01878*	-21.39	-0.018830*	-21.66	-0.019429*	-19.17	-165.3502*	-8.79
Income less 60K	-0.446888*	-17.40	-0.44857*	-17.36	-0.455481*	-17.80	-0.448193*	-15.02	-8239.7820*	-14.88
Num. Driver lic.	0.208989*	10.37	0.20853*	10.28	0.214503*	10.68	0.300551*	12.84	5009.7203*	11.53
Total Trips	0.043652*	10.13	0.04241*	9.79	0.042726*	9.95	0.112362*	22.45	3456.6742*	37.22
Num. Active Trips	-0.229339*	-35.85	-0.23015*	-35.78	-0.226116*	-35.44	-0.284790*	-38.29	-4340.5774*	-31.45
On Island	-0.029100	-0.81	-0.02531	-0.76	-0.154316*	-5.02	-0.194310*	-5.43	-1122.4333	-1.69
Dist Job Center	-0.000050*	-13.73	-0.00006*	-17.12	-0.000071*	-20.88	-0.000084*	-21.29	-1.2655*	-17.20
Num Retail	-0.000365*	-21.77	-0.00033*	-15.76	-0.000311*	-18.01	-0.000295*	-14.63	-1.6234*	-4.34
Food Sto. 10min	-0.000863*	-6.69	-0.00160*	-6.72	-0.000387*	-3.38	0.000550*	4.13	-30.2743*	-12.26
Num. Jobs 30 min	-0.000002*	-14.61	-	-	-	-	-	-	-	-
Num. workers 30 min	0.000002*	14.83	-	-	-	-	-	-	-	-
Gravity jobs	-	-	-0.00001*	-6.985	-	-	-	-	-	-
Gravity workers	-	-	0.00002*	5.888	-	-	-	-	-	-
Competition jobs	-	-	-	-	-0.020452*	-18.13	-0.019060*	-14.49	-426.6481	-17.48
(Constant)	-0.354551*	-4.505	-0.04069	-.507	0.395543*	5.51	16.170445*	193.22	34528.5519*	22.23
Dependent	ln(Sp. Conc.)		ln(Sp. Conc.)		ln(Sp. Conc.)		ln(Area)		Total Distance	
R Square	0.359		0.352		0.363		0.369		0.424	

*Indicate statistical significant at the 99% confidence level

The Influence of Accessibility on Spatial Dispersal

Three models are developed to test the impact of accessibility on the spatial dispersal factor. The first includes cumulative opportunity measures to workers and to jobs, the second uses gravity measures to workers and to jobs and the third use the inverse balancing factors measure for jobs. The highest R square is associated to the inverse balancing factors. In the first model, the number of jobs within 30 minutes of travel time has a negative effect on the spatial dispersal of the activity area. Although the effect is minor in term of the magnitude in the model (0.0002%), the number of jobs in the region that can be reached within 30 minutes of travel time ranges from 7900 to 1,400,000. Therefore, the level of accessibility to jobs has a statistically significant powerful effect on reducing spatial dispersal. Similarly, the number of workers that can be reached within 30 minutes of travel time leads to an increase in the spatial dispersal factor. The gravity measure shows a similar sign and power. This implies that households residing in areas with high accessibility to jobs are expected to have more spatially dispersed activity spaces, while individual's residing in areas with many competing workers may need to travel further to work. Finally using the inverse balancing factors enables to account for accessibility to jobs after accounting for competition, rather than use two variables that may interact unpredictably. This model shows the spatial dispersal factor is expected to decline by 2% for every unit increase in accessibility to jobs measured by the inverse balancing factor. This measure produces a relative unit of analysis making the interpretation less transparent. That being said, the results can be interpreted as showing a decline in spatial dispersion, leading to more compact and/or smaller activity space areas, in zones with higher job opportunities and less competing workers.

The last two models concentrate on the area and total distance traveled. The independent variables have similar effects on both these measures. In this model, we only used the inverse balancing factors as a measure of accessibility to jobs. The area of the activity space is expected to decline by 1.9% for every increase in the level of accessibility. Every unit of increase in accessibility levels is expected to decrease the total distances traveled by the household residents by 426 meters.

These models clearly show that regional accessibility levels are linked to household travel behaviour and accessibility levels. This effect is statistically significant using all three measures. The increase in the level of accessibility to jobs in general can have an effect on the total daily travel, the area covered by the household activity and/or the spatial concentration the activity area.

Hedonic Analysis

The second set of statistical models explores the relationship between housing prices and accessibility to jobs, workers and retail. The dependent variable is the sale price of the house in Canadian dollars. Table 3 includes a list and description of the variables used in the analysis as well as summary statistics. It is important to note that some variables that are common in other hedonic analysis, such as primary school levels, are not included due to the absence of these variables in the Canadian context.

As it was shown earlier the inverse balancing factors measure produced a better model when trying to understand the activity space. In this section of the analysis, we tested cumulative and gravity measures of accessibility to jobs and workers and we found a similar result. Accordingly, only the inverse balancing factors measure is used in this part of the analysis. As it is expected to produce, a better fit and disentangle job accessibility from the value of the central city.

Table 3: Variable name and summary statistics

Coefficient	Variable description	Mean	STD
Sale Value	Home sale value	267340.84	149663.71
Bedrooms	Number of bedrooms	2.81	0.81
Xtra Bathroom	Number of additional bathrooms	0.50	0.70
Num. Powder Room	Number of powder rooms	0.53	0.56
Num. Rooms	Total number of rooms	7.37	2.12
Building Age	Age of the house	37.94	28.34
Building Age squared	Age of the house squared	2241.96	3228.62
Association Fees	A dummy to indicate the presence of monthly fees	0.12	0.32
Living Area	Area of the living space in square meters	154.83	233.68
Log of Lot Area	Log of the lot area in square meters	6.07	0.74
Semi Detached	A dummy to indicate if the home type is semi-detached	0.23	0.42
Attached	A dummy to indicate if the home type is attached	0.19	0.39
Employees	Number of people in the labour force residing in the census tract of the home	2701.48	1103.97
Neigh. Median Income	Median income of the census tract	59871.68	22954.00
Renovations	Average amount in dollars spent by home owners on renovations in the census tract	1000.63	188.34
Neigh University degree	Percentage of persons holding a university degree residing in the census tract	35.08	16.63
On the island	A dummy variable indicating if the home is on Montréal island	0.53	0.50
Num. Retail	Number of retail opportunities within a 1km buffer of the home	262.80	380.36
Dist to Job Center	Network distance to the nearest job center	8037.37	7096.09
Food Stores 10min	Number of food stores within 10 minutes travel time by car	99.80	111.60
Competition jobs	Inverse balancing factor for jobs	10.38	9.38

The Impact of Accessibility

The results of the hedonic regression show the expected signs and power for the building and neighbourhood characteristics. In keeping with other studies [33], accessibility increases the fit of the model by approximately 2%. For every increase in the level of accessibility home sale values increases by $1005.03. As it is shown in table 4, the mean value of the accessibility measure was 10.38. Accordingly, a person purchasing a $250,000 house with a mean level of accessibility of 10.38, will be paying around 4.17% towards the level of accessibility that this house offers to him. The number of food stores within 10 minutes travel time by car is a better variable than the count of retail within a 1 km buffer of the house. Each food store within 10 a minute drive increase the value of the house by 301.23$. Each meter between the house and the nearest job center decreases the value by 1.55$, reinforcing again the high values associated with proximity to business centers.

Table 4: Hedonic analysis

Coefficients	Base model		Balancing factors	
	B	t	B	t
Bedrooms	22144.96*	6.045	23193.17*	6.462
Xtra Bathroom	57451.60*	15.296	53471.36*	14.458
Num. Powder Room	27797.39*	5.781	28941.35*	6.150
Num. Rooms	6360.47*	4.135	6990.93*	4.639
Building Age	-1054.66*	-3.987	-1232.83*	-4.755
Building Age squared	8.57*	4.000	8.74*	4.166
Association Fees	-41774.66*	-4.987	-41428.67*	-5.045
Living Area	43.80*	4.397	45.12*	4.630
Log of Lot Area	37788.12*	8.950	41343.74*	9.969
Semi Detached	15955.83**	2.371	8437.90	1.272
Attached	22533.01*	2.704	13243.01	1.611
Employees	-16.75*	-6.663	-12.88*	-5.162
Neigh. Median Income	0.39**	2.305	0.83*	4.841
Renovations	196.90*	9.335	170.56*	8.150
Neigh University degree	906.30*	3.802	617.05*	2.634
On the island	23730.57*	3.414	26136.72*	3.622
Num. Retail	47.10*	5.738	-	-
Dist to Job Center	-1.57*	-3.466	-1.55*	-3.497
Food Stores 10min	-	-	301.23*	9.756
Competition jobs	-	-	1005.03*	3.381
(Constant)	-322608.61	-10.622	-370280.97*	-12.199
R Square	0.558		0.577	

*Significant at the 99% confidence level
**Significant at the 95% Confidence level
Dependent variable: sales price

The inverse balancing factors gave better results in the model than the cumulative opportunity and gravity measured gave in previous tests. Accessibility to workers gave a positive sign in previous tests, indicating it might be acting as a proxy for high-density central areas. The Employees variable, which corresponds to the number of people in the labour force living in the house’s census tract, had the expected sign in both models, however it’s power decreased when the inverse balancing factors was incorporated to the model, indicating competition is accounted for at the regional level by this measure.

Sustainable Land Use and Travel Patterns

As shown by the hedonic regression (Table 4) regional accessibility to jobs and retail are capitalized in home sale values. According to urban economic theory, increasing regional accessibility will, in theory, increase the land bid for these areas, which will in turn increase land values. This added-value effect should generate competition and should translate into higher density development in accessibility rich areas. This could eventually lead to smaller, more concentrated activity spaces and shorter travel distances, favouring the use of active modes of transportation. Accessibility-oriented policies can influence household travel behaviour and location, giving rise to more compact and mixed cities. Observing the distribution of the spatial dispersal variable in the Montreal region in Figure 4 it is clear that some of the fringes need more work in term of increasing their level of regional accessibility to jobs. This can be done through either providing more jobs in these areas or providing adequate means of transportation to job rich areas. Finally, transportation policies that aim at increasing regional accessibility need to be developed with an in-depth understanding of personal travel behaviour and household activity space.

CONCLUSION

This study explores the relationships between regional accessibility and household travel behaviour and location choices. In order to study household travel behaviour, a new measure of the actual activity space is introduced: the spatial dispersal factor. The spatial dispersal factor accounts for the compactness and the scale of the activity space. It can be used as a proxy for household and personal accessibility. The actual activity space can also be used as a base for measures of personal accessibility; however acquiring data for the availability of opportunities at such a fine scale is difficult and issues relating to scale and compactness may arise. In addition, the absence of time spent at destination is a critical obstacle in generating time space prism measures. The actual activity space is a good measure to evaluate the impacts of regional accessibility levels on travel behaviour. The spatial dispersal can be starting point to develop new space-time measures of accessibility.

Regional accessibility to jobs is measured using the inverse balancing factors of the doubly constrained spatial interaction model. This measure accounts for competition and give a significantly more accurate spatial representation of accessibility. The measure is incorporated to the models and it improved the fit of the models while maintaining the statistical significance of most variables more than the traditional cumulative opportunity and gravity measures. It is recommended to use this measure in the future. Yet it is important to note that the calculation of this measure requires some basics of computer programming.

Regional accessibility is found to have a statistically significant effect on the spatial dispersal the area of the activity space, and the total distance traveled. This suggests that policies favouring regional accessibility to jobs and workers can lead to more compact and sustainable travel patterns. Regional accessibility is also found to have a statistically significant effect on housing prices. This result highlights again the value of regional accessibility to individuals and households and opens the door for policies aiming to increase density and mixed land use patterns.

Regional accessibility combines the location of people, places and activities, and the geography of transportation in the same measure. It enables a comprehensive approach to transportation and land-use planning and favours more sustainable outcomes such as higher-densities, shorter travel distances and more local, spatially dispersed travel patterns. It is important to note that competitive measures of accessibility can also be generated for specific job markets, yet for simplicity reasons in this research paper, we used accessibility to jobs and to workers in general. We hope the limited analysis presented here will, have shown the importance of the approach and its usefulness in transportation planning and policies.

ACKNOWLEDGMENTS

The authors would like to thank Mr. Pierre Tremblay from the Québec Ministry of Transportation for providing the travel time used in the analysis. This work was partially funded through an accessibility project funded by Québec Ministry of Transportation and the Natural Science and Engineering Research Council of Canada (NSERC). Also would like thank Mr. Daniel Bergeron of the AMT for providing the detailed Montréal OD survey used in the analysis. We would like to thank La Fédération des chambres immobilières du Québec for providing the MLS data used in this analysis. The authors would like to thank Mohamed Sabry Hassouna, Vital Images and Ahmed Ayad, Microsoft Corp. for their help and advice during the conceptualization phase of the spatial dispersal measure. Last but not least, we would like to thank Prof. Raphael Fischler for his feedback at various stages of this project. All opinions in this paper are the responsibility of the authors.

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